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Comparison Study of Models Used to Prescribe Hydrometeor Water Content Values

Part II: USSR Data

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Three "models" for inferring atmospheric liquid water content from conventional weather data are compared on the basis of a large sample of predictions for 11 stations in the USSR. Two of the three models were developed at the Air Force Geophysics Laboratory; the third is the Smith-Feddes model of the Air Weather Service. Comparison is in terms of integrated liquid water content and the environmental severity index. For want of independent measurements of water content, no light is shed on the absolute accuracy of these models.

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Preface

R.W. Lenhard and R.M. Peirce were principals at the outset of this study. The AFGL-1 sample was generated by H. Dolan of Analysis and Computer Systems, Inc. The basic AFGL-2 profiles were the product of joint effort by Environmental Research and Technology, Inc. and the Meteorology Laboratory of the Air Force Cambridge Research Laboratories. The further processing of these data was in the hands of S.-L. Tung and A.J. Bussey of ERT. The ETAC sample was provided by the USAF Environmental Technical Applications Center (Air Weather Service). J. Young shepherded the graphics and manuscript through their meanderings. The draft was constructively reviewed by M.L. Barad, I.I. Gringorten, M.J. Kraus, I.A. Lund, and V.G. Plank.

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1. INTRODUCTION

The stuff that clouds are made of can be a decisive factor of military importance; such as, the erosion of exposed surfaces on high-speed vehicles and the attenuation of electromagnetic radiation along a path through the atmosphere. The mass concentration of hydrometeors is a property of frequent concern, but size distribution and other parameters also play a significant role at times. The term "hydrometeor" encompasses water particles of all sizes, the large ones called precipitation, as well as the smaller cloud particles.

Throughout this report, the mass concentration of all hydrometeors, including snow and ice in any form, will be called liquid water content (LWC). The imprecise qualifier "liquid" serves as a remainder that which is not included in LWC is water, in the gaseous phase, which is almost invariably the more massive.

LWC and the other microphysical properties of hydrometeors are not observed routinely by the weather services of the world. Consequently, there are no archives on which to base climatologies of these parameters. Instead, short of instituting a special observational program, one can generate such a climatology only indirectly, through the use of correlations established between the hydrometeoric parameter of interest and weather parameters that are observed routinely and archived. The latter was the approach of the Environmental Definition Program (EDP) conducted

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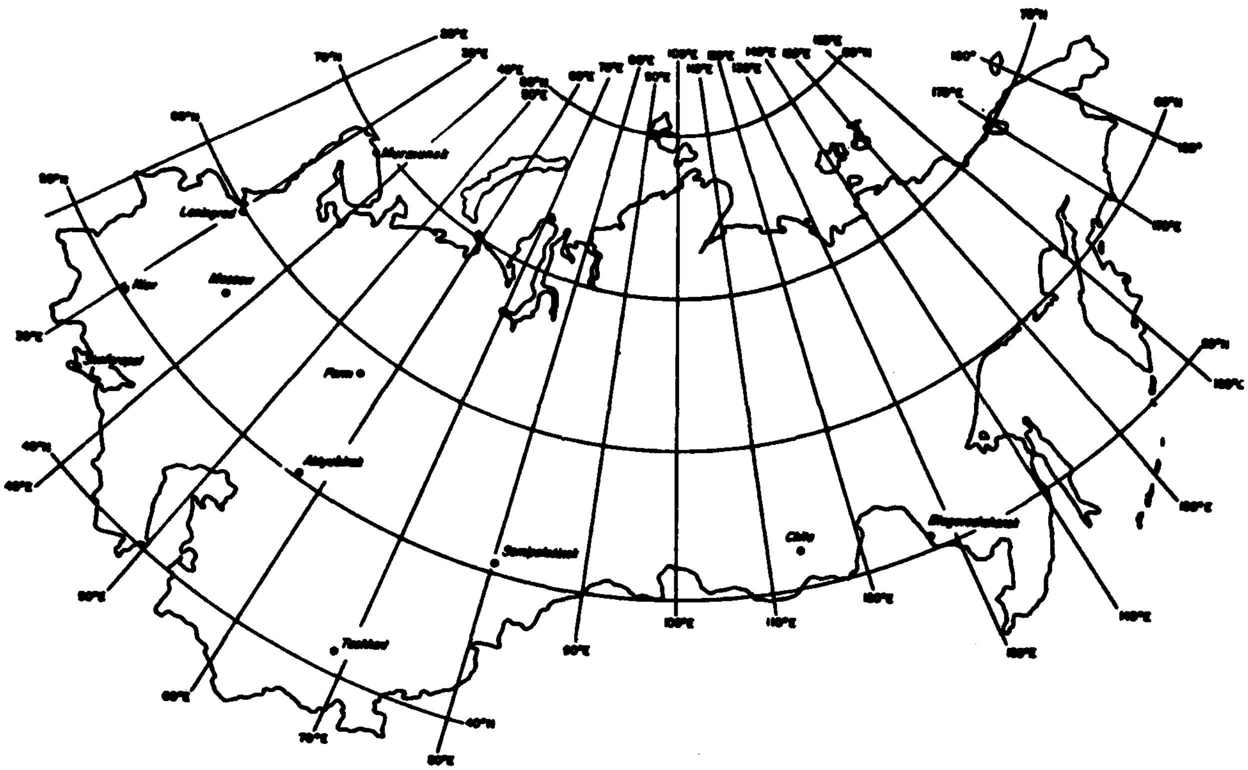

Figure 1. Geographical Distribution of the Eleven USSR Stations of the Environmental Definition Program

during the years 1973-1977 by the Air Force Geophysics Laboratory (AFGL). One of the more ambitious endeavors of this program was the "11-station study" based on AFGL's second-generation EDP "model" commonly called AFGL-2.*

The 11-station study entailed the synthesis of a year-long record of the vertical distribution of LWC for each of 11-stations in the USSR. These stations, which were selected for the supposed diversity of their LWC climates as well as for the availability of suitable meteorological records, are identified in Table 1 and their locations shown in Figure 1. For each of the stations and for every three hours of the 12-month period starting 1 February 1973, a vertical profile of LWC was derived. Thus the ultimate product of the 11-station study was some 32,000 profiles of LWC.

This report treats one of the spin-offs of the 11-station study, namely an intercomparison of three different LWC models: AFGL-1, AFGL-2, and ETAC.

Table 1. The Eleven USSR Stations of the Environmental Definition Program

Station Number	Name	Latitude	Longitude
221130	Murmansk	68°58'N	33°03'E
260630	Leningrad	59°58'N	30°18'E
276120	Moscow	55°58'N	37°25'E
333450	Kiev	50°24'N	30°27'E
339460	Simferopol	45°01'N	33°59'E
282250	Perm	58°01'N	56°18'E
352290	Aktyubinsk	50°20'N	57°13'E
361770	Semipalatinsk	50°21'N	80°15'E
384570	Tashkent	41°16'N	69°16'E
307580	Chita	52°01'N	113°19'E
315100	Blagoveschensk	50°16'N	127°30'E

2. MODELS

In all three of the models, values of LWC are inferred from standard weather data. The basic difference among the models is in the specifics of this parameterization.

*Prior to 1976 what is now AFGL was part of the Air Force Cambridge Research Laboratories (AFCRL), which no longer exists. In this earlier time, AFGL-2 was known as AFCRL-2.

AFGL-1 is an automated decision tree which employes as input a sounding of temperature and humidity plus a surface report of precipitation and cloud type.

AFGL-2 is based on a manually analyzed vertical time-section (altitude vs. time) incorporating all meteorological data that are systematically available for the particular location. Presently they are: surface synoptic reports, upper air reports, the Northern Hemisphere Maps published by the National Oceanic and Atmospheric Administration (NOAA), the three-dimensional nephanalysis (3DNEPH) of the Air Force Global Weather Center (AFGWC), and imagery products of the Defense Meteorological Satellite Program. Wherever clouds or precipitation are reckoned to have existed on this time-section, values of LWC are assigned according to typical values for the class of hydrometeor, temperature, and other circumstances.[1,2]

"ETAC" is the title used here for the Smith-Feddes LWC model of the Air Weather Service. It is an automated procedure which employs as input 3DNEPH and upper-air temperatures from the AFGWC northern hemisphere analysis,[3,4]

The output of these three models has already been compared with independently measured profiles of LWC by Peirce et al,[5] but the number of cases (29 at most) was too small to support much confidence in the findings. The present study remedies this size defect, based on 4,000-10,000 profiles for each model, but totally lacks an absolute reference in the form of directly measured LWC.

3. DATA BASE OF THE COMPARISON

To provide a sample of all seasons, the months of February, May, July, and October, 1973, were chosen for the comparison. (The rationale for this disjointed selection is lost in the unrecorded past.)

For each of the 11 USSR stations, three-hour LWC profiles by AFGL-2 already existed. The USAF Environmental Technical Applications Center matched these

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1. Cunningham, R.M. and Peirce, R.M. (1974) Environmental Definition Plan Cross Section Analysis, Internal Report of the Meteorology Laboratory, AFCRL.
2. Feteris, P.J., Lisa, A.S., and Bussey, A.J. (1975) Environmental Definition Program Cross Sectional Analysis: Summary of Data and Analysis Technique, AFCRL-TR-76-0002, AD A024 707.
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4. Smith, R.D. (1974) Atmospheric Moisture Parameterization, USAFETAC TN 74-1.
5. Peirce, R.M., Lenhard, R.W., and Weiss, B.F. (1975) Comparison Study of Models Used to Prescribe Hydrometeor Water Content Values, Part I: Preliminary Results, AFCRL-TR-75-0470, AD A019 633.

with three-hour profiles by ETAC. Since AFGL-1 requires a radiosounding as explicit input, its profiles were limited to intervals of six hours. Consequently, the AFGL-1 sample is roughly half the size of the other two. The grand totals are 4343 profiles for AFGL-1, 10, 648 for AFGL-2, and 8255 for ETAC. One station-month out of the 44 is missing for AFGL-1, and three are missing for ETAC. The average number of LWC profiles in the station-month sample is 101 for AFGL-1, 242 for AFGL-2, and 201 for ETAC.

AFGL-1 is designed to specify only the LWC contained in precipitation-sized particles, that is, particles larger than 50 μm in diameter. (For ice particles the relevant diameter is that of the melted drop.) For comparison, then, only the precipitation component of the other two models was used. For ETAC this means the sum of two classes: cloud-rain liquid (CRL) and cloud-rain ice (CRI). For AFGL-2 it is the sum of all classes of explicit precipitation plus 10 percent of the LWC in cumulonimbus plus one percent of the LWC in other cumuliform low clouds. (In AFGL-2 all forms of ice are classed as precipitation.)

Another constraint on LWC is in terms of the horizontal extent of the layer of precipitation. In the ETAC and AFGL-2 profiles the water content of a layer was ignored unless the layer covered at least five-tenths of the sky. AFGL-1 has no information on the sky coverage of individual layers. In these profiles, then, the LWC was taken to be 0 throughout whenever the surface observer reported a total sky coverage of less than four-eighths. This black-or-white treatment of a layer or of the entire profile is a first-order device for factoring into the statistics the probability that a randomly positioned vertical will encounter the particular LWC profile.

The models are intercompared in terms of two integrals of the profile of LWC: integrated LWC (ILWC) and the Environmental Severity Index (ESI).

$$\mathrm{ILWC} \equiv \int_0^\infty M\,dz$$

$$\mathrm{ESI} \equiv \int_0^\infty z\,M\,dz$$

where

M is LWC in (kg m^{-3}) for ILWC, in (g m^{-3}) for ESI

Z is height in (m) for ILWC, in (km) for ESI

so that

ILWC is in kg m^{-2}

ESI is in g km^2 m^{-3}

(ESI is a parameter of particular concern in the erosion of ballistic reentry vehicles.)

All three models are compared in terms of ILWC. However, for want of appropriate data on ETAC, only AFGL-1 and AFGL-2 are compared in terms of ESI.

Both frequency distributions and averages are used as yardsticks for the comparison. Averages for ETAC were derived from the frequency distributions, which were the only form of these data available. The raw ETAC averages were adjusted by a factor of 0.655 to compensate for inflation relative to the averages for AFGL-1 and AFGL-2, which were derived from individual profiles. In the process of evaluating an average from a distribution, the entire population of a class is assigned the mid-value of ILWC for that class. Inflation in the present instance arises mainly in the first class, 0-0.1 kg m^{-2}, for which the true mean must be sensibly less than 0.05 owing to the large but unknown number of "clear" profiles. An indication of this preponderance is the fact that the median ILWC for AFGL-2 is 0 in all 44 of the station-month samples. It was 11 of these samples, well distributed with respect to ILWC, which were averaged by both methods (from the distribution and from the individual profiles) to arrive at the factor by which the raw ETAC averages were adjusted.

4. RESULTS AND DISCUSSION

Detailed results are displayed in the Appendix. Figures A1 through A11 in the Appendix show the cumulative frequency distributions of ESI. (For any value of ESI the plot pegs the fraction of the profiles in the sample having that value of ESI or larger.) With rare exception, the AFGL-2 curve drops sharply down to less than 10 percent exceedance at an ESI of less than five. Occasionally the curve tails off to the upper limit of the plot. By contrast, AFGL-1 drops less sharply, begins to flare in the mid-range of exceedance, and carries on to higher values of ESI. Almost invariably, then, AFGL-1 lies above AFGL-2.

A similar relation between these two models is exhibited in Figures A12 through A22 in the Appendix which show the cumulative frequency distributions of ILWC for all three models. ETAC's behavior is rather intermediate in the left portion of the plot. Typically it falls off as sharply as AFGL-2 but begins to flare somewhere

between AFGL-1 and AFGL-2. Frequently ETAC crosses AFGL-1 in tailing off and winds up the topmost curve in the right portion of the plot.

Station-month averages of ESI are compared in the bar graphs of Figures A23 and A24 in the Appendix. With but one exception, AFGL-1 averages higher than AFGL-2, frequently by a sizeable amount.

The corresponding averages of ILWC are compared in Figures A25 and A26, now for all three models. Again AFGL-1 is larger than AFGL-2 with one exception, but ETAC is larger yet for most samples and exceeds AFGL-1 by a substantial margin in many cases.

The same comparison of averages, but in numerical terms, is made in Table 2 for ESI and in Table 3 for ILWC. (For convenience, AFGL-1 and AFGL-2 are abbreviated to "GL-1" and "GL-2".)

The contrast is more sharply focused in Table 4 where the average ESI for AFGL-1 is quoted as a multiple of the corresponding value for AFGL-2. This factor ranges from 0.88 to 27 with an overall average of 3.8. (The "average" ratios are, throughout, ratios of the appropriate averages, not averages of ratios.)

Table 2. Average Values of ESI (g km^2 m^{-3}) for AFGL-1 and AFGL-2

Station	FEB		MAY		JUL		OCT	
	GL-1	GL-2	GL-1	GL-2	GL-1	GL-2	GL-1	GL-2
MUR	4.64	0.17	2.95	0.44	1.01	0.07	5.88	0.77
LEN	3.35	0.26	2.82	0.43	1.29	0.38	4.26	0.67
MOS	3.10	0.69	2.28	1.33	3.20	0.50	3.67	0.71
KIE	2.76	0.42	1.65	0.64	1.85	0.57	1.78	1.28
SIM	2.96	0.88	2.39	0.38	0.61	0.23	1.65	0.84
PER	4.14	0.12	2.38	0.23	3.76	4.28	5.28	0.55
AKT	1.85	0.27	4.16	0.31	2.85	0.18	2.29	1.20
SEM	M	0.22	1.59	0.13	2.13	2.08	2.26	0.66
TAS	1.94	0.38	1.53	1.47	0.25	0.04	1.09	0.14
CHI	1.94	0.16	3.58	0.24	4.13	3.91	1.68	0.12
BLA	1.97	0.23	4.01	0.58	3.06	0.83	1.07	0.12
AVERAGE	2.87	0.36	2.67	0.56	2.19	1.19	2.81	0.64

Table 3. Average Values of ILWC (kg m^{-2}) for All Three Models

Station	FEB			MAY			JUL			OCT		
	GL-1	GL-2	ETAC	GL-1	GL-2	ETAC	GL-1	GL-2	ETAC	GL-1	GL-2	ETAC
MUR	1.05	0.06	4.43	0.61	0.09	3.17	0.12	0.02	1.19	1.31	0.29	1.41
LEN	0.85	0.12	1.30	0.44	0.07	1.68	0.18	0.08	0.59	1.06	0.26	2.57
MOS	0.80	0.23	1.79	0.32	0.25	0.26	0.49	0.12	1.01	0.68	0.24	1.12
KIE	0.58	0.18	0.39	0.27	0.15	M	0.28	0.12	M	0.32	0.30	M
SIM	0.58	0.20	1.98	0.40	0.06	1.49	0.09	0.04	0.22	0.24	0.19	0.55
PER	0.86	0.05	1.99	0.44	0.05	0.55	0.64	0.80	2.00	1.08	0.19	5.34
AKT	0.38	0.12	0.34	0.64	0.07	1.76	0.41	0.04	1.33	0.39	0.28	0.78
SEM	M	0.08	0.18	0.22	0.02	1.79	0.38	0.33	1.83	0.31	0.18	0.45
TAS	0.29	0.10	0.45	0.22	0.24	0.42	0.04	0.01	0.05	0.17	0.04	0.22
CHI	0.32	0.03	0.18	0.58	0.06	0.48	0.61	0.78	1.15	0.28	0.02	0.08
BLA	0.34	0.05	0.05	0.66	0.14	0.71	0.38	0.16	1.24	0.17	0.03	0.96
AVERAGE	0.61	0.11	1.29	0.45	0.11	1.23	0.33	0.24	1.06	0.57	0.17	1.95

Table 4. The ESI Ratio (AFGL-1/AFGL-2)

Station	FEB GL-1/GL-2	MAY GL-1/GL-2	JUL GL-1/GL-2	OCT GL-1/GL-2
MUR	27	6.7	14	7.6
LEN	13	6.6	3.4	6.4
MOS	4.5	1.7	6.4	5.2
KIE	6.6	2.6	3.2	1.4
SIM	3.4	6.3	2.7	2.0
PER	35	10	0.88	9.6
AKT	6.9	13	16	1.9
SEM	-	12	1.0	3.4
TAS	5.1	1.0	6.3	7.8
CHI	12	15	1.1	14
BLA	8.6	6.9	3.7	8.9
AVERAGE	8.0	4.8	1.8	4.4

Average values of ILWC, quoted as multiples of AFGL-2, are listed in Table 5. The range of GL-1/GL-2 is from 0.78 to 18 with an overall average of 3.1. For ETAC/GL-2 the range is from 0.92 to 89 with an overall average of 8.5.

The gyrations of these ratios make more sense when it is recognized that they exhibit a distinct trend with magnitude of ESI or ILWC. Figure 2 is a log-log plot of the ESI ratio GL-1/GL-2 vs. ESI according to GL-2. This reveals that in the 43 station-month samples, the average value of ESI specified by GL-1 is more than twice the GL-2 value only when the ESI is less than 1 g km^2 m^{-3}. On the regression line the overall average multiple of 3.8 occurs at an ESI of less than 0.7. The two models are equal at an ESI of about four, and at larger values, presumably, the GL-2 values of ESI exceed those specified by GL-1.

Figure 3 is the analogous plot for ILWC. It shows that in the 43 USSR samples, the average value of ILWC specified by GL-1 is more than twice the GL-2 value only for an ILWC of less than 0.3 kg m^{-2}. The overall average multiple of 3.1 occurs at an ILWC of 0.14 on the regression. The two models are equal at an ILWC of about 1, and at larger values GL-2 appears to exceed GL-1.

Table 5. The ILWC Ratios (AFGL-1/AFGL-2) and (ETAC/AFGL-2)

Station	FEB		MAY		JUL		OCT	
	GL-1/GL-2	ETAC/GL-2	GL-1/GL-2	ETAC/GL-2	GL-1/GL-2	ETAC/GL-2	GL-1/GL-2	ETAC/GL-2
MUR	18	74	6.8	35	6	59	4.5	26
LEN	7.1	11	6.3	24	2.3	7.4	4.1	9.9
MOS	3.5	7.8	1.3	1.0	4.1	8.4	2.8	4.7
KIE	3.2	2.1	1.8	-	2.3	-	1.1	-
SIM	2.9	9.9	6.7	25	2.3	5.6	1.3	2.9
PER	17	40	8.8	11	0.80	2.5	5.7	28
AKT	3.2	2.8	9.1	25	10	33	1.4	2.8
SEM	-	2.3	11	89	1.2	5.6	1.7	2.5
TAS	2.9	4.5	0.92	1.7	4.0	5.2	4.3	5.6
CHI	11	6.1	9.7	8.0	0.78	1.5	14	3.9
BLA	6.8	0.92	4.7	5.1	2.4	7.7	5.7	32
AVERAGE	5.5	12	4.1	11	1.4	4.4	3.4	11

Figure 3 also includes five points based on the results obtained by Peirce et al.[5] Their 29 cases have been averaged in five subsets according to magnitude of ILWC: three for the so-called SAMS data and two for EDPX. Clearly the Peirce points follow the same trend as the USSR. All points were used in the regression, although the USSR points have the greater influence due to their tenfold advantage in sample size.

One adjustment had to be made in the Peirce data before they were properly comparable with the USSR data. Peirce evaluated AFGL-2 LWC for all hydrometeors present regardless of size, whereas AFGL-2 was limited to precipitation-sized particles in the USSR data. In the 44 USSR samples for AFGL-2 it was found that, on the average, total ILWC exceeds precipitation ILWC by a factor of 3.0. This, then, was the multiplier applied to the raw ratios GL-1/GL-2 of the Peirce data before inclusion in Figure 3.

The comparison between ETAC and GL-2 is shown in Figure 4, which also includes Peirce points, but now only three points because of the smaller total number of pairs. The trend of the ETAC/GL-2 ratio is almost identical to that of

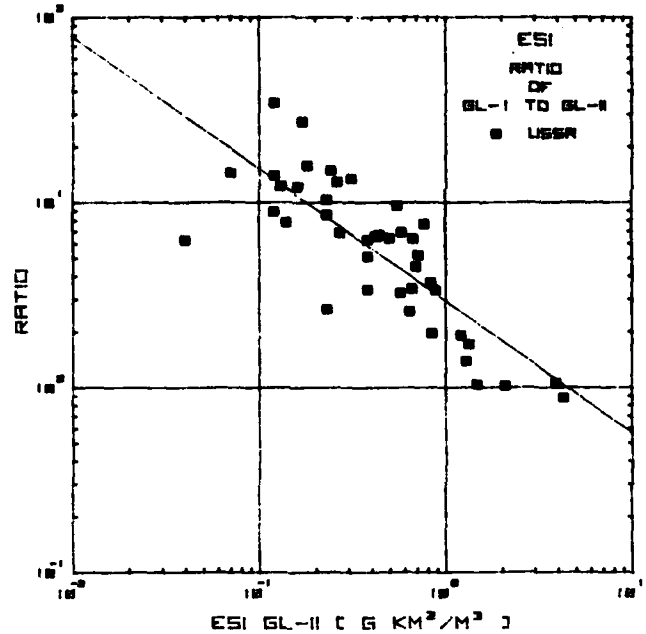

Figure 2. Variation of the ESI Ratio (GL-1/GL-2) with ESI (GL-2)

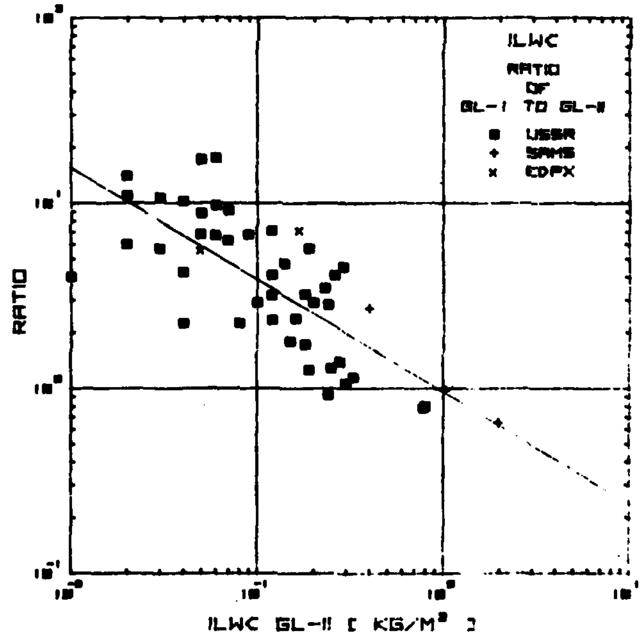

Figure 3. Variation of the ILWC Ratio (GL-1/GL-2) with ILWC (GL-2)

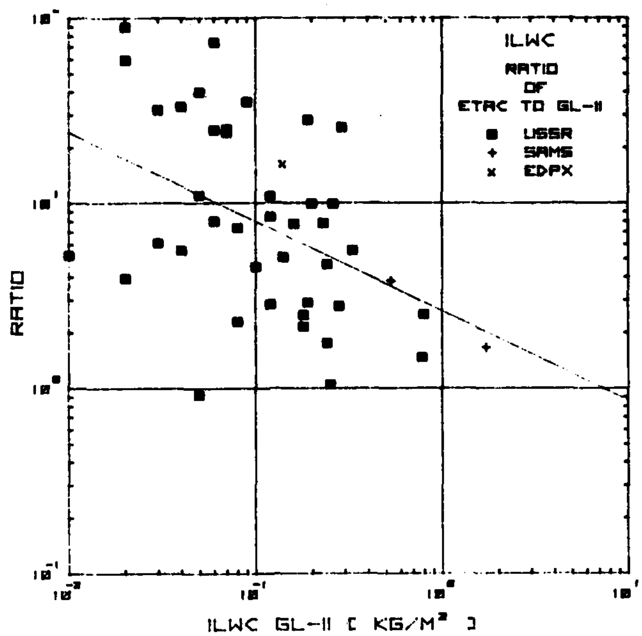

Figure 4. Variation of the ILWC Ratio (ETAC/GL-2) with ILWC (GL-2)

GL-1/GL-2, except that the regression is displaced upward by about a factor of 2, and the point of equality between ETAC and GL-2 is at an ILWC in excess of 7 kg m^{-2}.

The near parallelism between the regression line for GL-1 on GL-2 and that for ETAC on GL-2 suggests that ETAC and GL-1 may be linearly related: this is true, more or less. Direct regression yields the following relation for ILWC:

$$ETAC = 3.9(GL\text{-}1) - 0.58$$

The correlation coefficient is 0.79, and the standard error of the regression is 0.92 kg m^{-2}. The linear relation is a nearly optimum fit for these data, as is evidenced by the fact that regression in the log-log plane yields an exponent of 1.08.

A conceivable cause of the trend in the ratios of Figures 2 to 4 is that the absolute bias of GL-2 varies appropriately with magnitude. However, this possibility is not sustained by the 29 cases of the Peirce set. Log-log correlation of the ratio observed/GL-2 with GL-2 yields a coefficient of only 0.17. At all levels of ILWC the points bracket the overall average rather evenly.

5. CONCLUSION

The data analyzed here are sufficient to provide definitive comparison of the three LWC models at high temperate latitudes, for all seasons, and over a wide range of climates.

Overall comparisons are shown in Figure 5. Relative to AFGL-2, both AFGL-1 and ETAC overpredict at low values of ILWC or ESI and underpredict at higher values. Relative to AFGL-1, ETAC first underpredicts, then overpredicts.*

Parameters of these regressions are given in Table 6. Except for (d) the regressions are log-log; hence the standard errors are in terms of factors rather than increments. The standard error of regression for individual LWC profiles should be much larger since the regressions here were developed from averages of hundreds of profiles.

Table 6. Regression Relations Among the Three Models. (Units of ILWC are kg m^{-2}; ESI is in g km^2 m^{-3}. r is the correlation coefficient. S. E. is the standard error of regression.)

		r	S. E.
a) ESI:	$GL\text{-}1 = 2.9\ (GL\text{-}2)^{0.29}$	0.47	Factor of 1.7
b) ILWC:	$GL\text{-}1 = 0.96\ (GL\text{-}2)^{0.40}$	0.55	Factor of 1.8
c) ILWC:	$ETAC = 2.6\ (GL\text{-}2)^{0.52}$	0.45	Factor of 2.8
d) ILWC:	$ETAC = 3.9\ (GL\text{-}1) - 0.58$	0.79	0.92

An incidental product of this study is a statistical relationship between ILWC and ESI:

$$ILWC = 0.185\ (ESI) + 0.0310$$

with a standard error of 0.0419 kg m^{-2}. Conversely,

$$ESI = 5.05\ (ILWC) - 0.112$$

*Any of the three models can be easily retuned by changing values in the lookup tables. The ETAC sample here represents the Smith-Feddes model as of early 1975. Whether it remains precisely the same today is unknown.

with a standard error of 0.219 g km^2 m^{-3}. The correlation coefficient is 0.967. The 44 samples of USSR station-month averages for AFGL-2 are the basis of these relations.

For want of independent measurements of LWC, this report is unable to comment on the tentative conclusion of its predecessor (Peirce et al[5]) to the effect that AFGL-2 overpredicts ILWC by 29 percent on average.

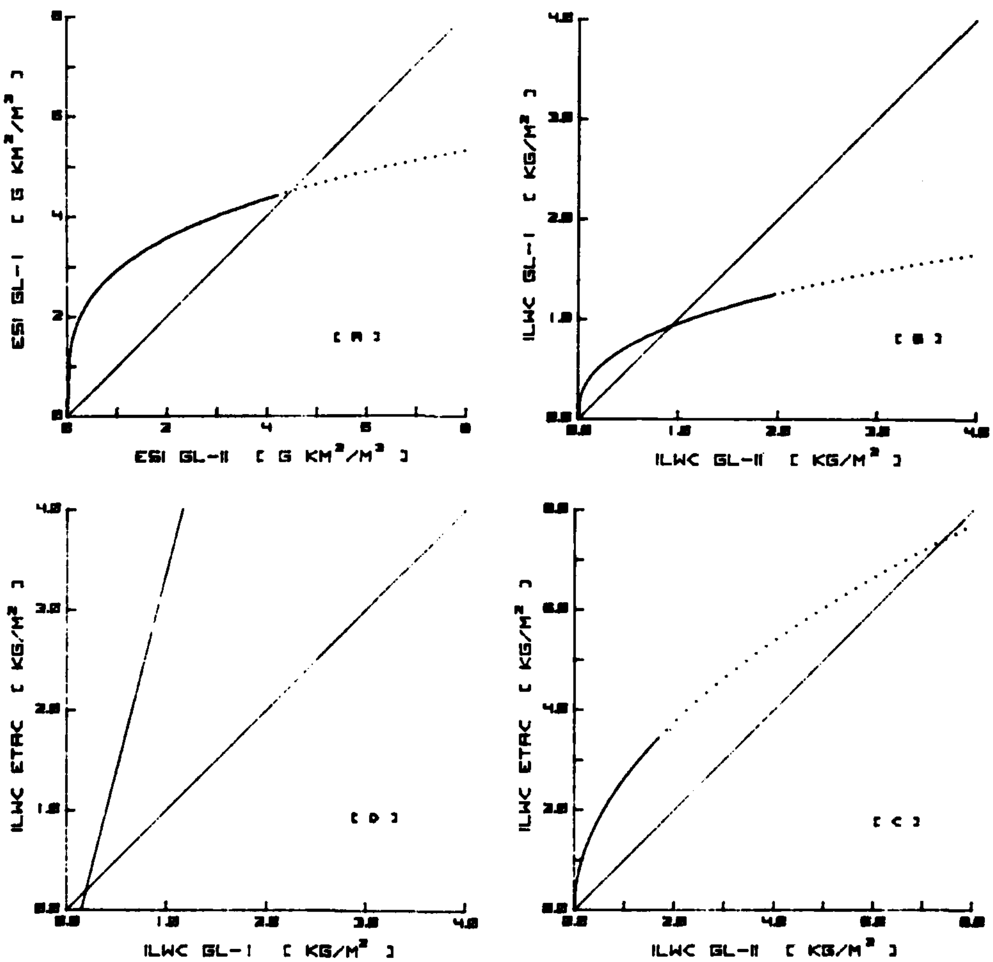

Figure 5. Overall Comparisons of the Three Models. a) ESI: GL-1 vs GL-2. b) ILWC: GL-1 vs GS-2. c) ILWC: ETAC vs GL-2. d) ILWC: ETAC vs GL-1. (The dotted segments are extensions of regressions beyond the range of data on the abscissa.)

References

1. Cunningham, R.M. and Peirce, R.M. (1974) Environmental Definition Plan Cross Section Analysis, Internal Report of the Meteorology Laboratory, AFCRL.

2. Feteris, P.J., Lisa, A.S., and Bussey, A.J. (1975) Environmental Definition Program Cross Sectional Analysis: Summary of Data and Analysis Technique, AFCRL-TR-76-0002, AD A024 707.

3. Feddes, R.G. (1974) A Synoptic-Scale Model for Simulating Condensed Atmospheric Moisture, USAFETAC TN 74-4.

4. Smith, R.D. (1974) Atmospheric Moisture Parameterization, USAFETAC TN 74-1.

5. Peirce, R.M., Lenhard, R.W., and Weiss, B.F. (1975) Comparison Study of Models Used to Prescribe Hydrometeor Water Content Values, Part I: Preliminary Results, AFCRL-TR-75-0470, AD A019 633.

Appendix A

Detailed Results of Comparison Study of Models

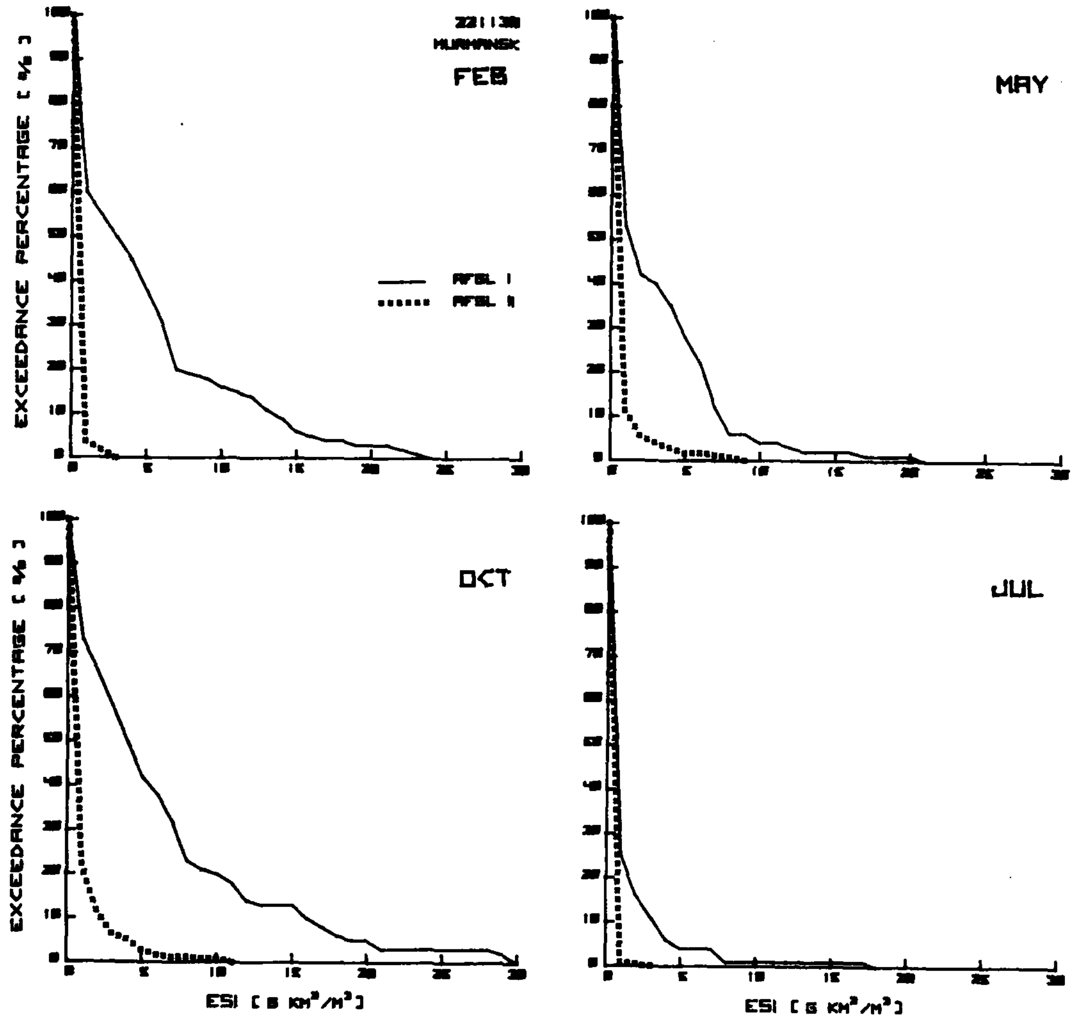

Figure A1. Cumulative Frequency Distribution of ESI for Station 221130, Murmansk

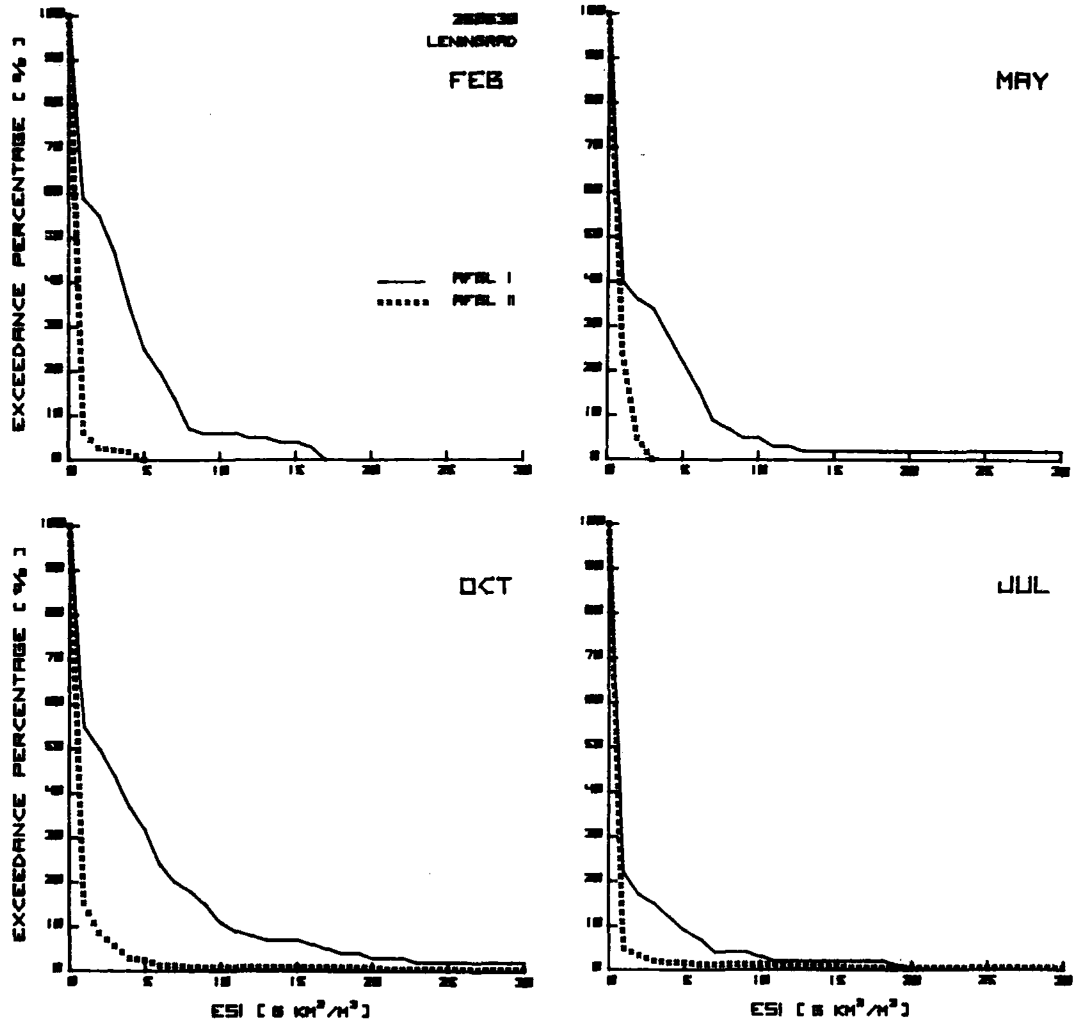

Figure A2. Cumulative Frequency Distribution of ESI for Station 260630, Leningrad

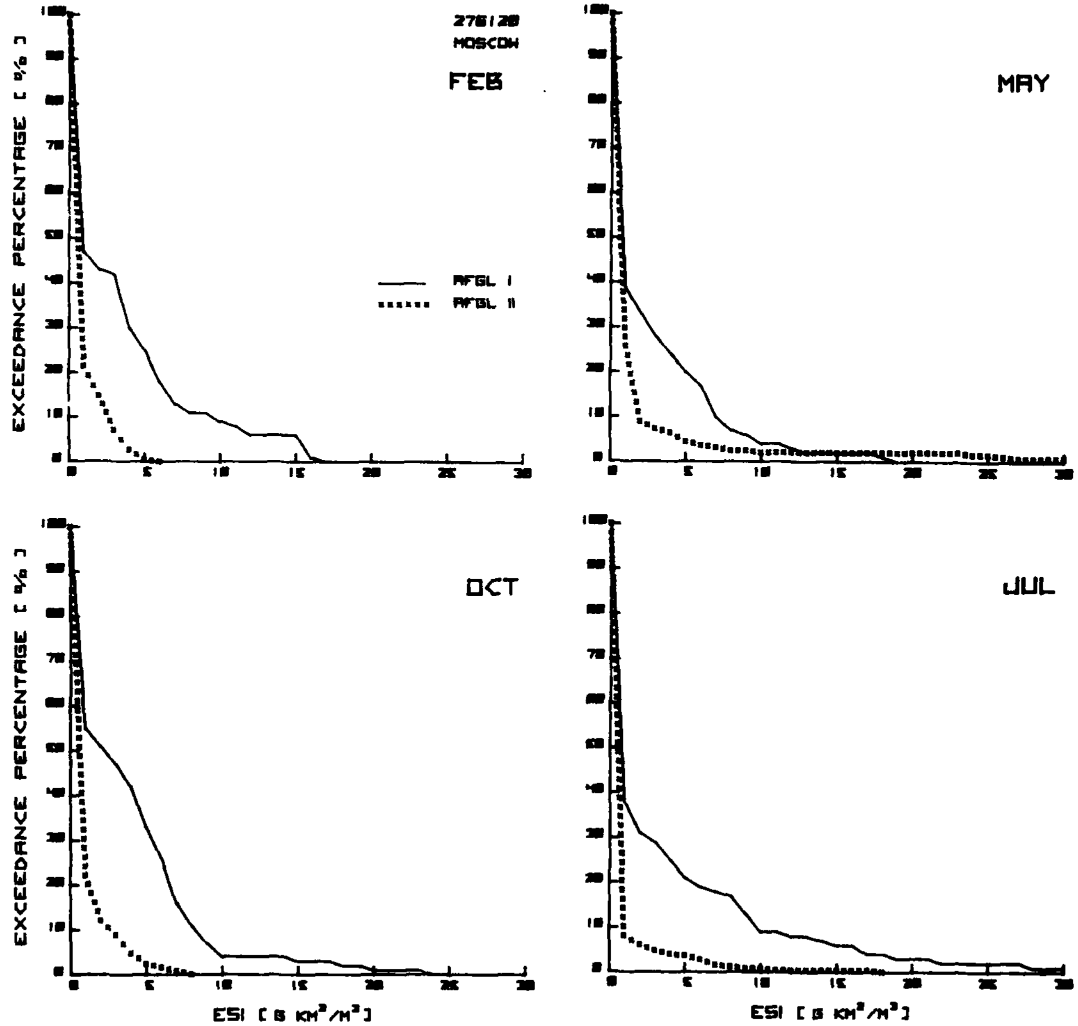

Figure A3. Cumulative Frequency Distribution of ESI for Station 276120, Moscow

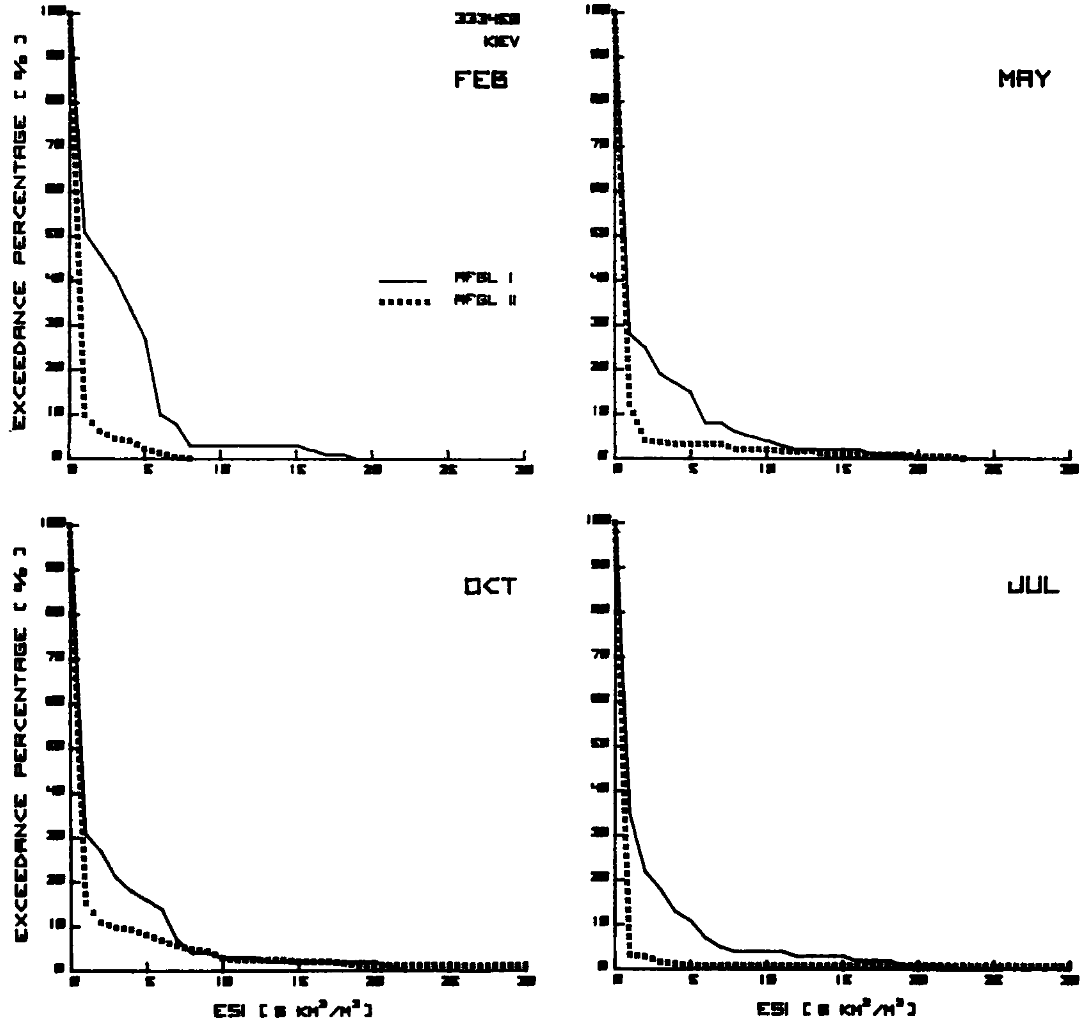

Figure A4. Cumulative Frequency Distribution of ESI for Station 333450, Kiev

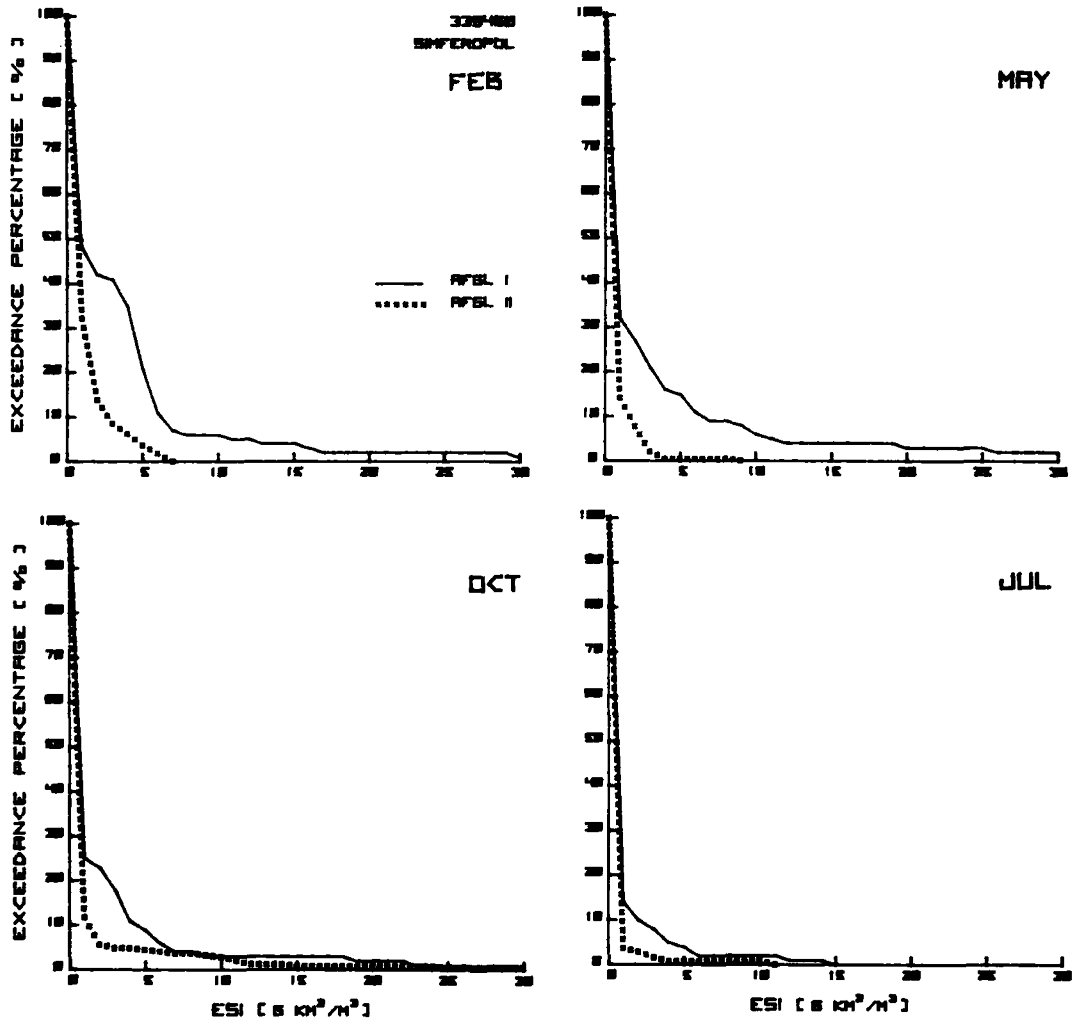

Figure A5. Cumulative Frequency Distribution of ESI for Station 339460, Simferopol

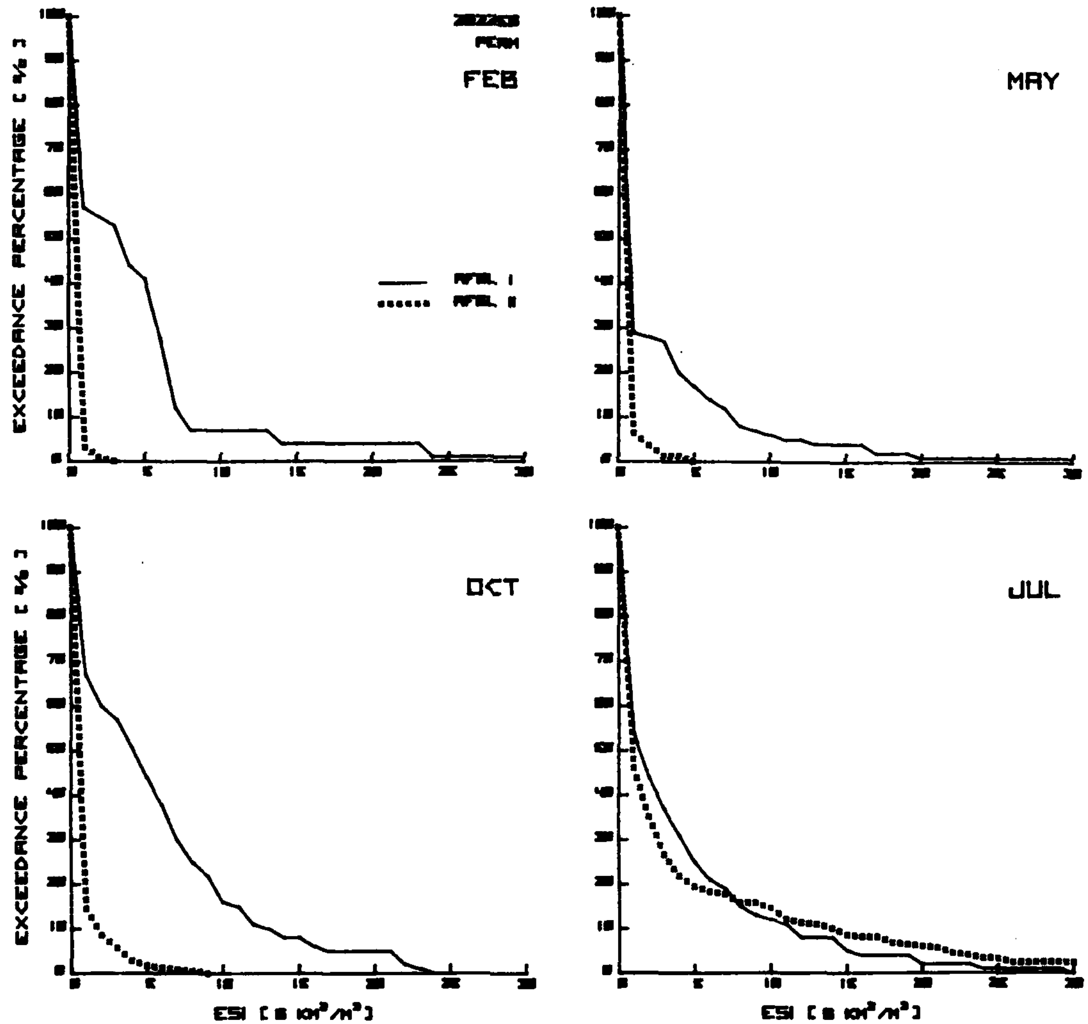

Figure A6. Cumulative Frequency Distribution of ESI for Station 282250, Perm

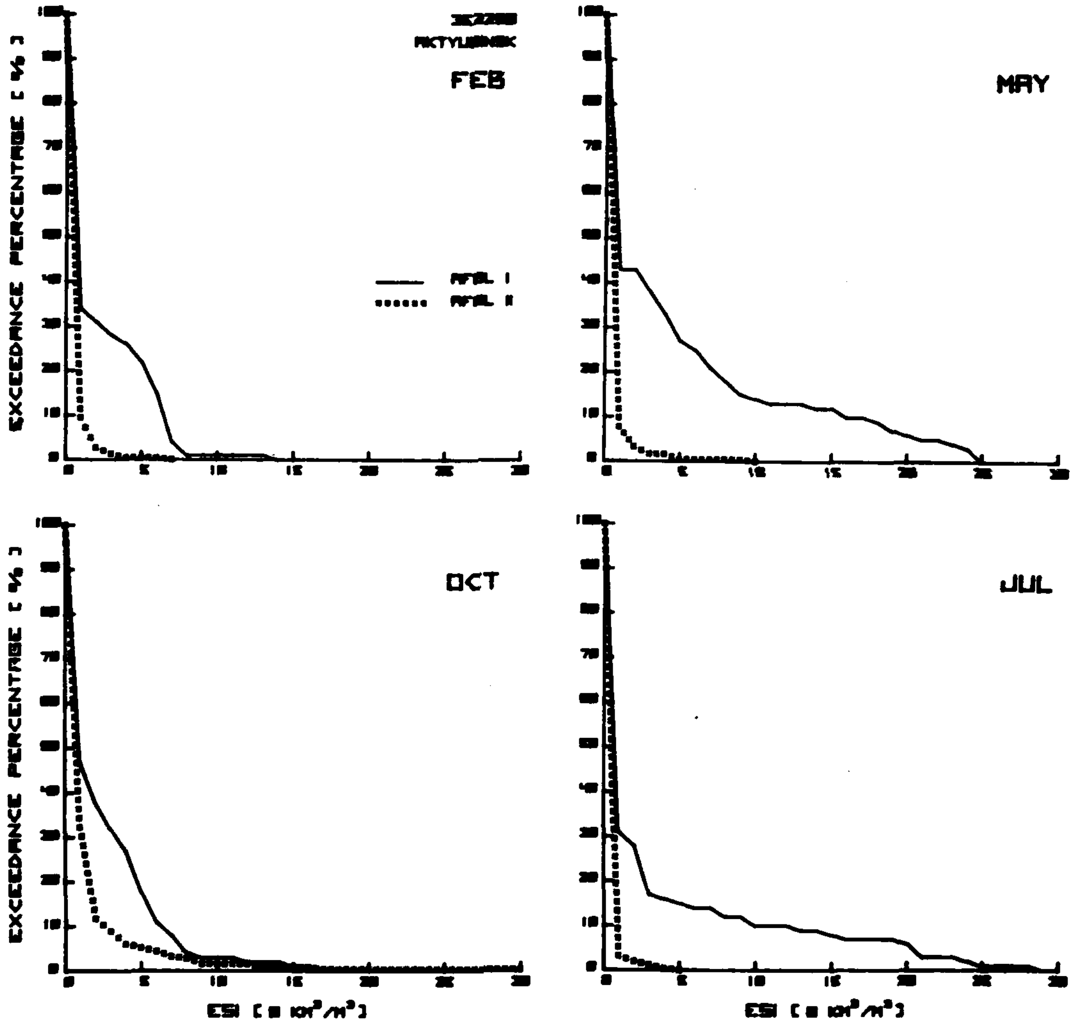

Figure A7. Cumulative Frequency Distribution of ESI for Station 352290, Aktyubinsk

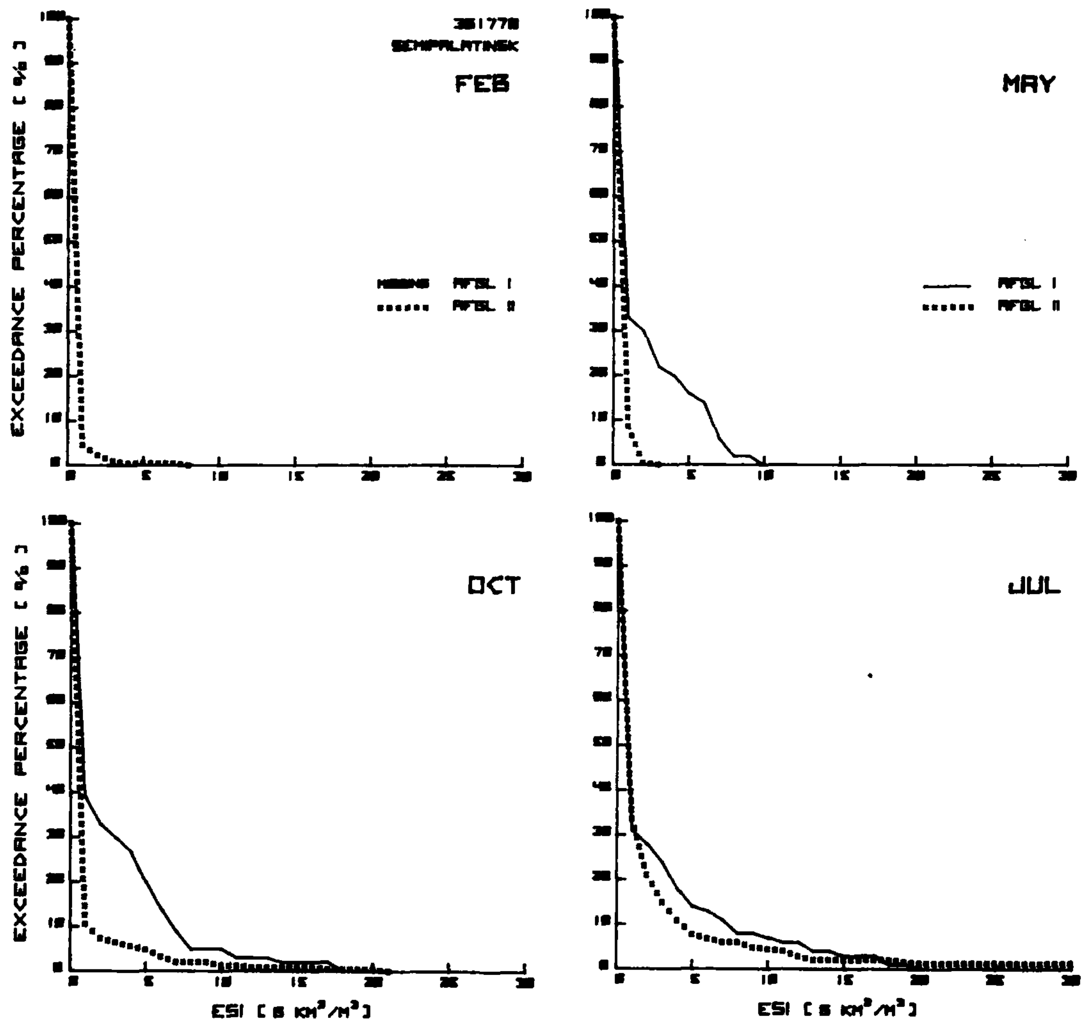

Figure A8. Cumulative Frequency Distribution of ESI for Station 361770, Semipalatinsk

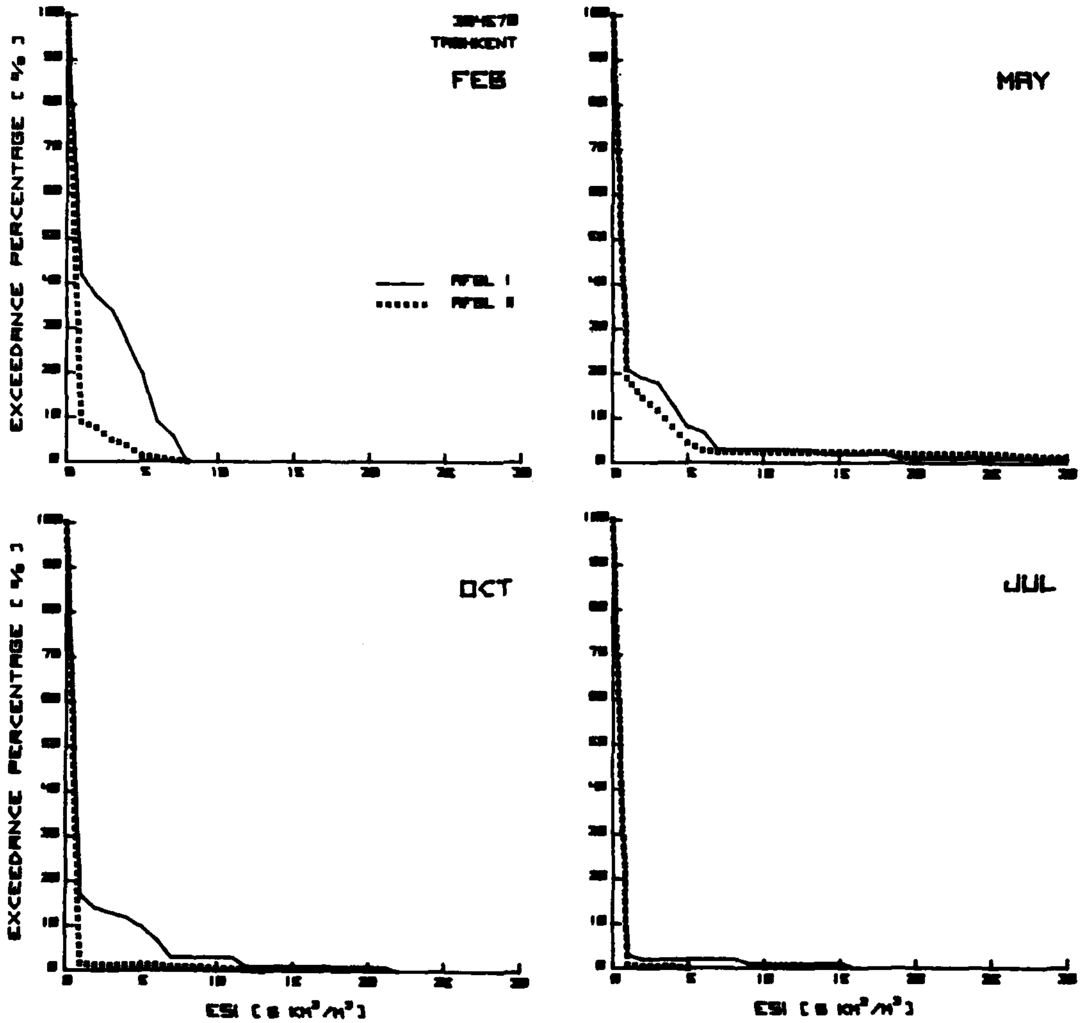

Figure A9. Cumulative Frequency Distribution of ESI for Station 384570, Tashkent

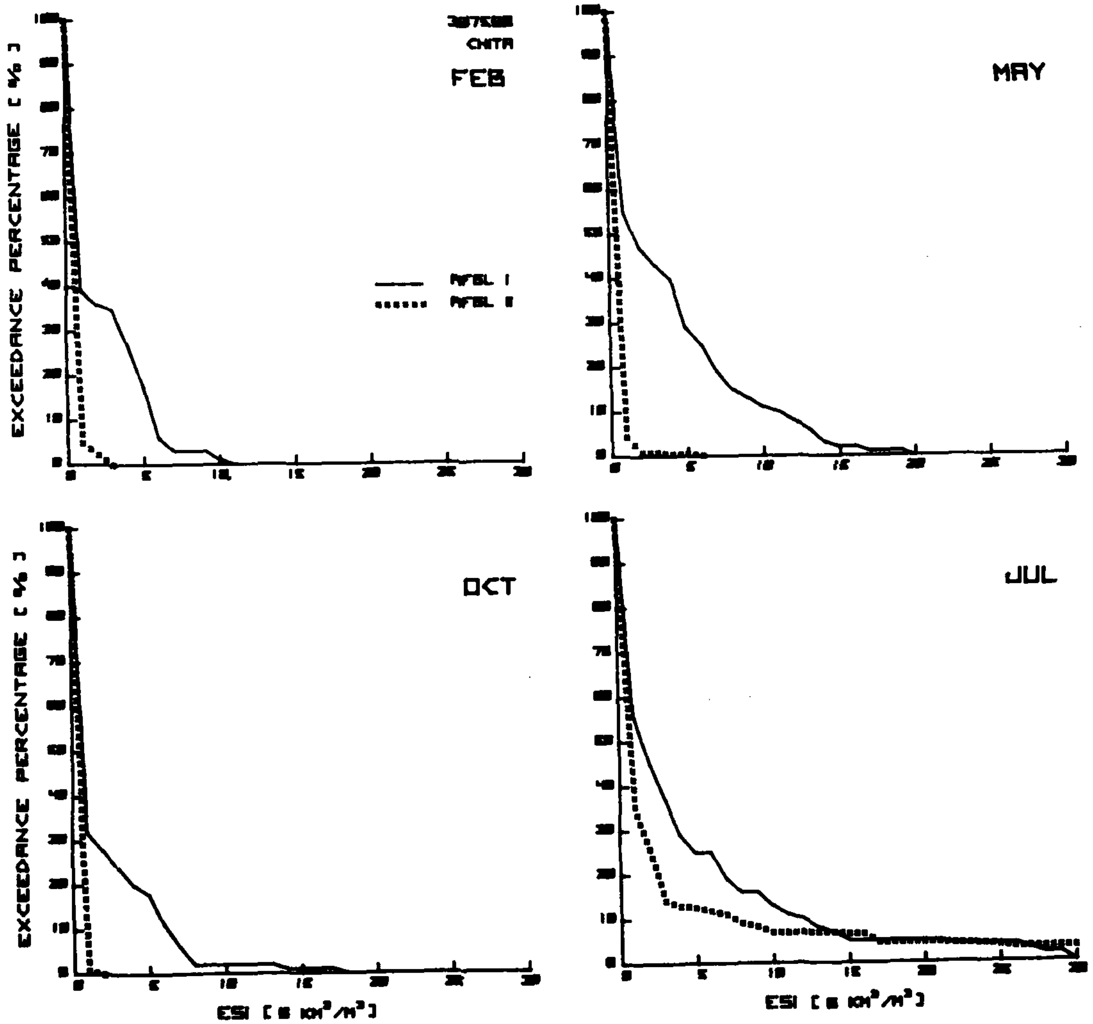

Figure A10. Cumulative Frequency Distribution of ESI for Station 307580, Chita

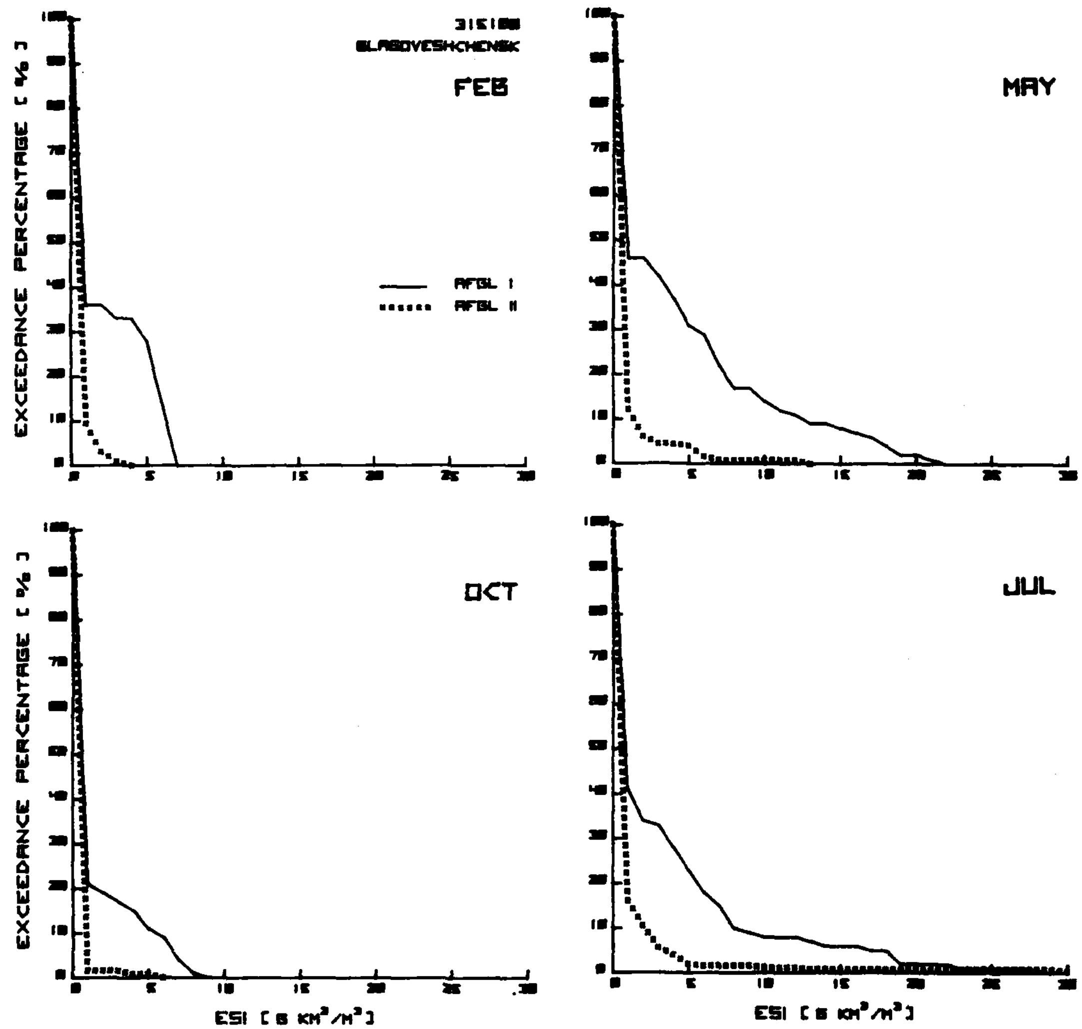

Figure A11. Cumulative Frequency Distribution of ESI for Station 315100, Blagoveschensk

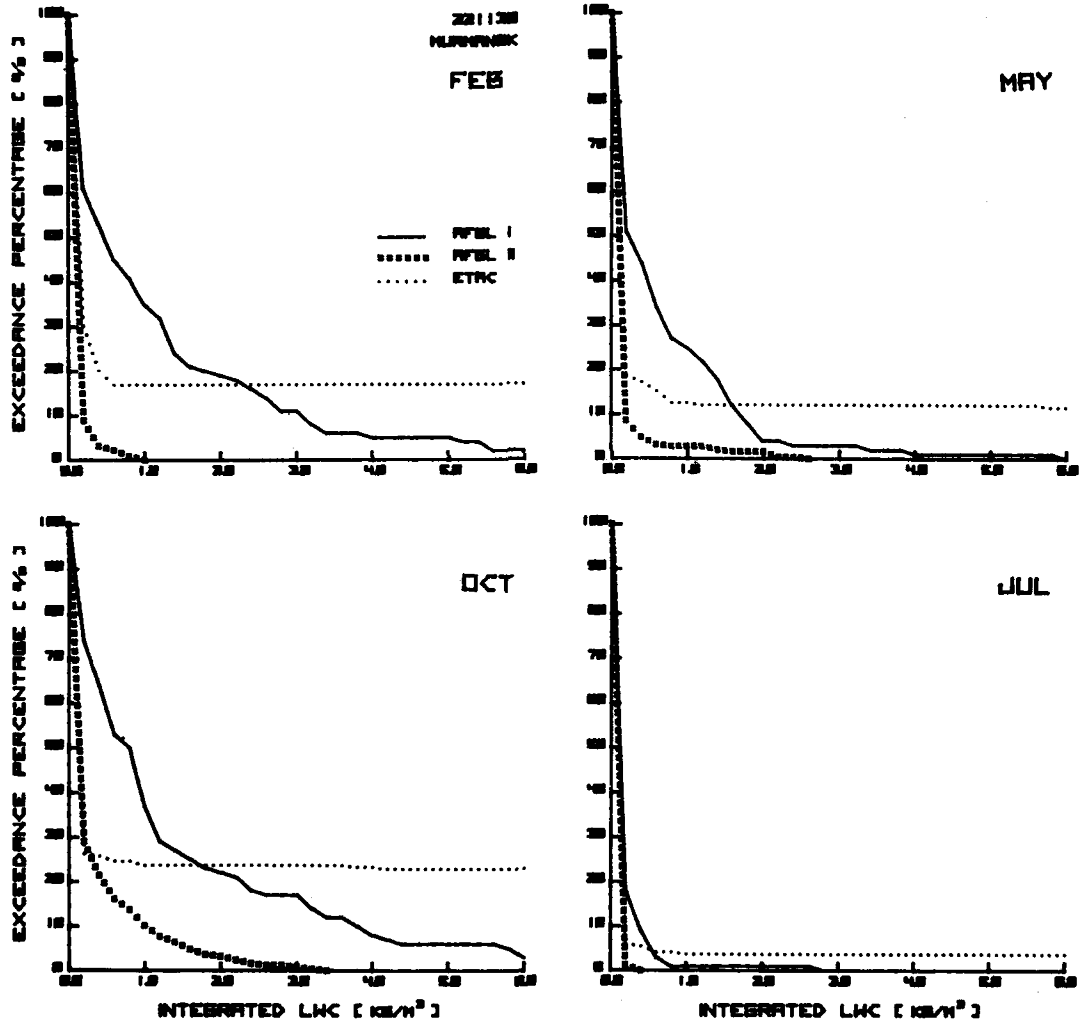

Figure A12. Cumulative Frequency Distribution of ILWC for Station 221130, Murmansk

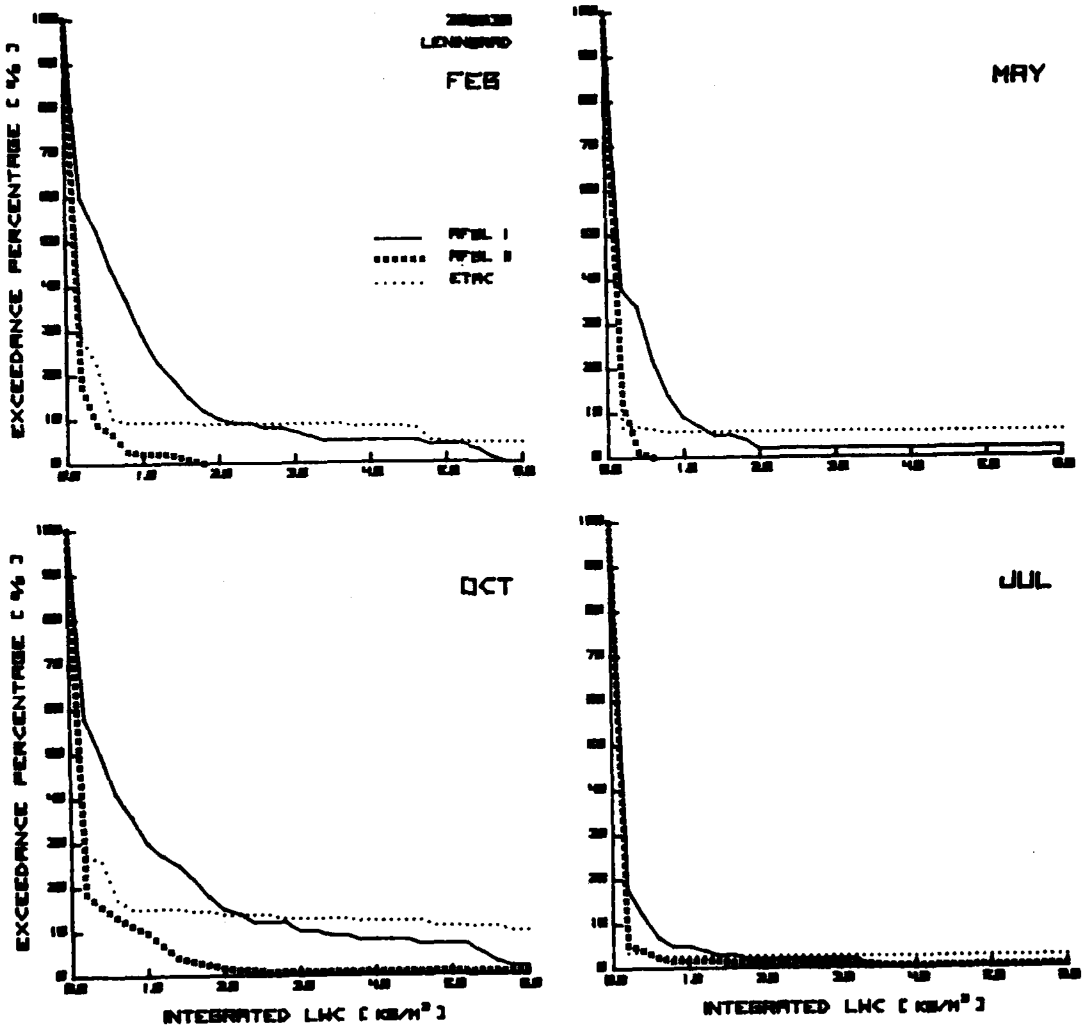

Figure A13. Cumulative Frequency Distribution of ILWC for Station 260630, Leningrad

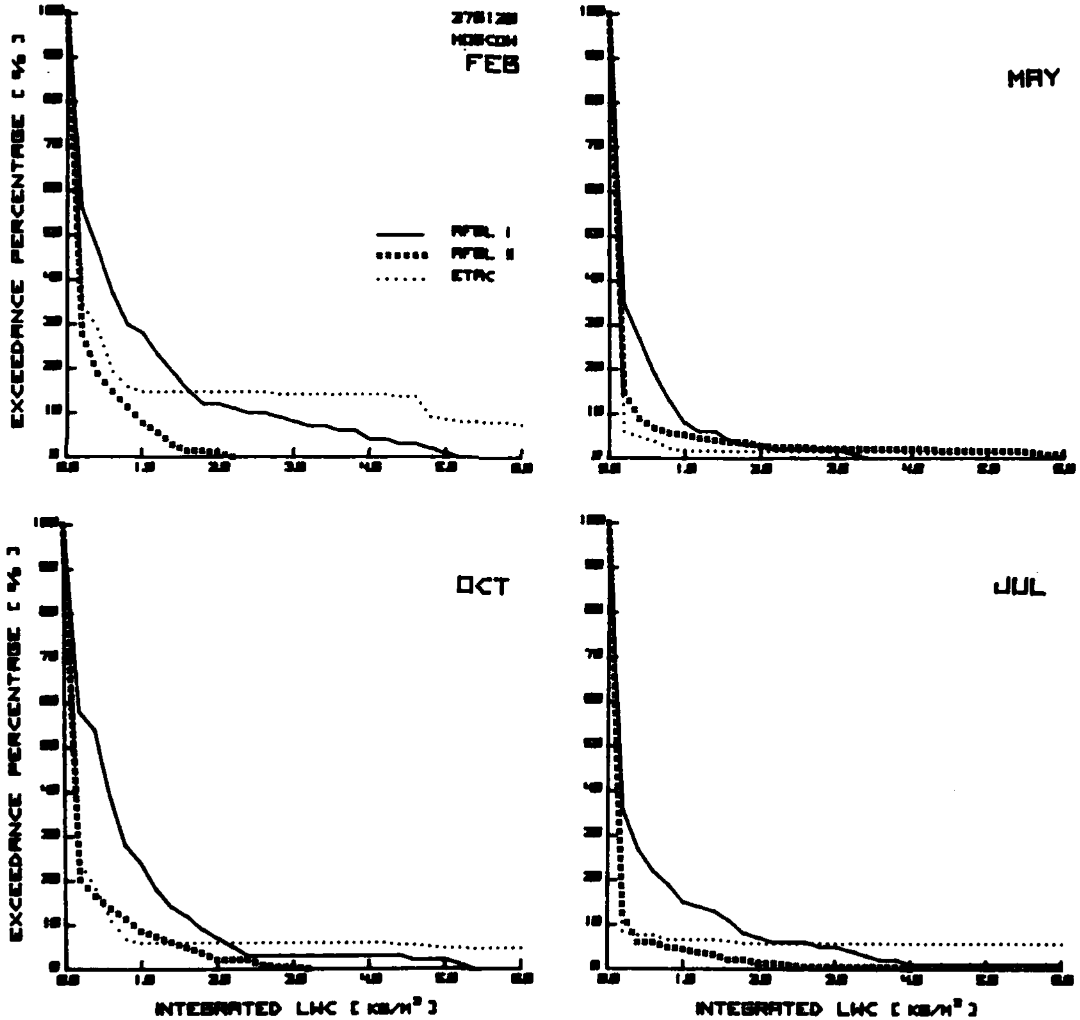

Figure A14. Cumulative Frequency Distribution of ILWC for Station 276120, Moscow

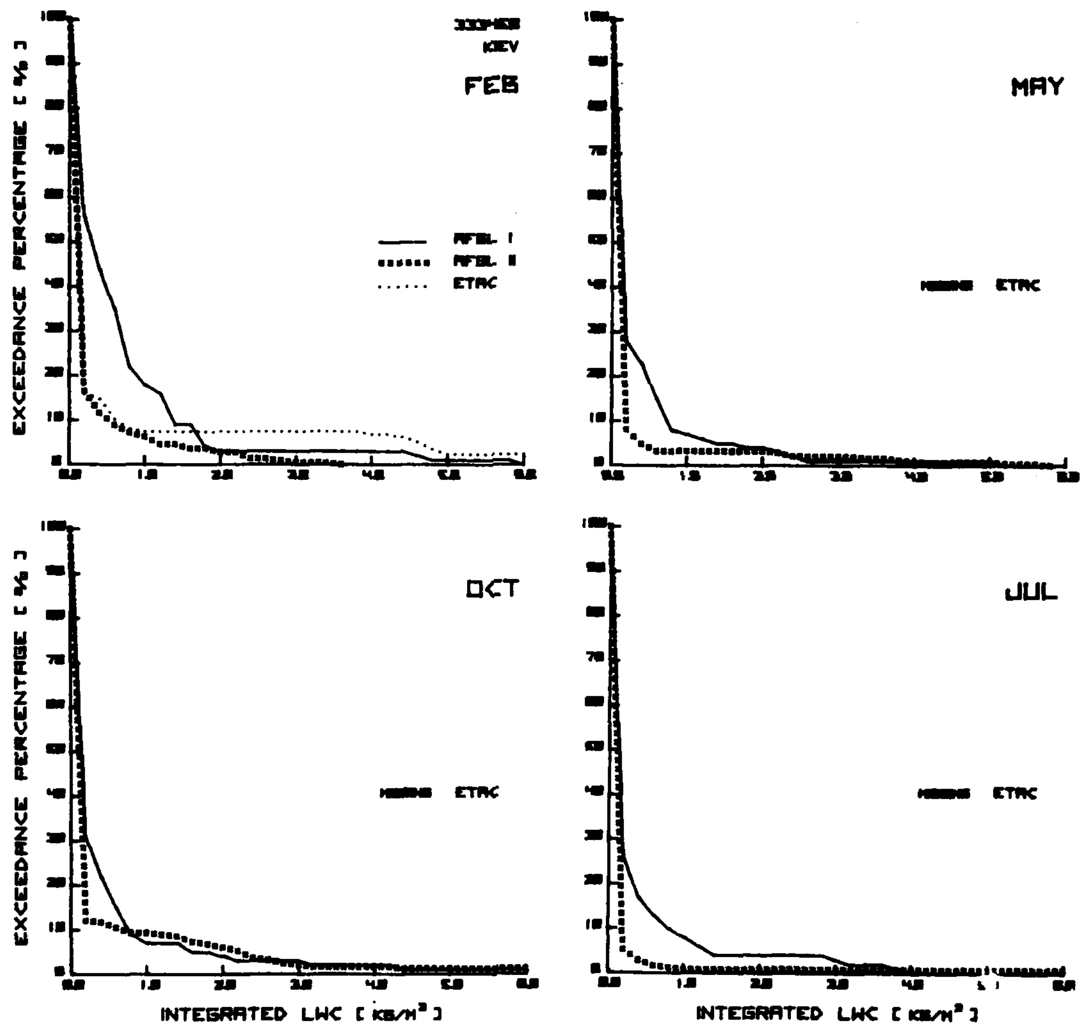

Figure A15. Cumulative Frequency Distribution of ILWC for Station 333450, Kiev

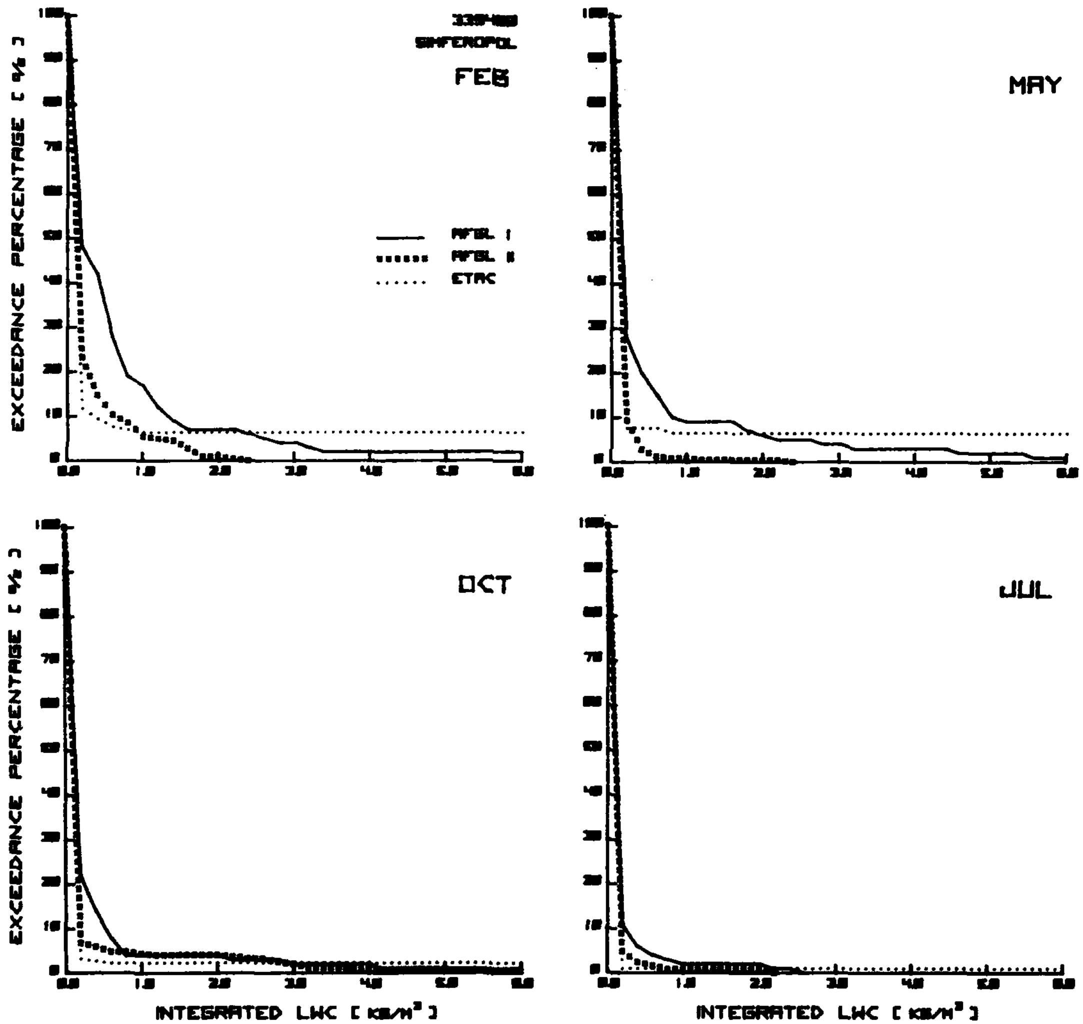

Figure A16. Cumulative Frequency Distribution of ILWC for Station 339460, Simferopol

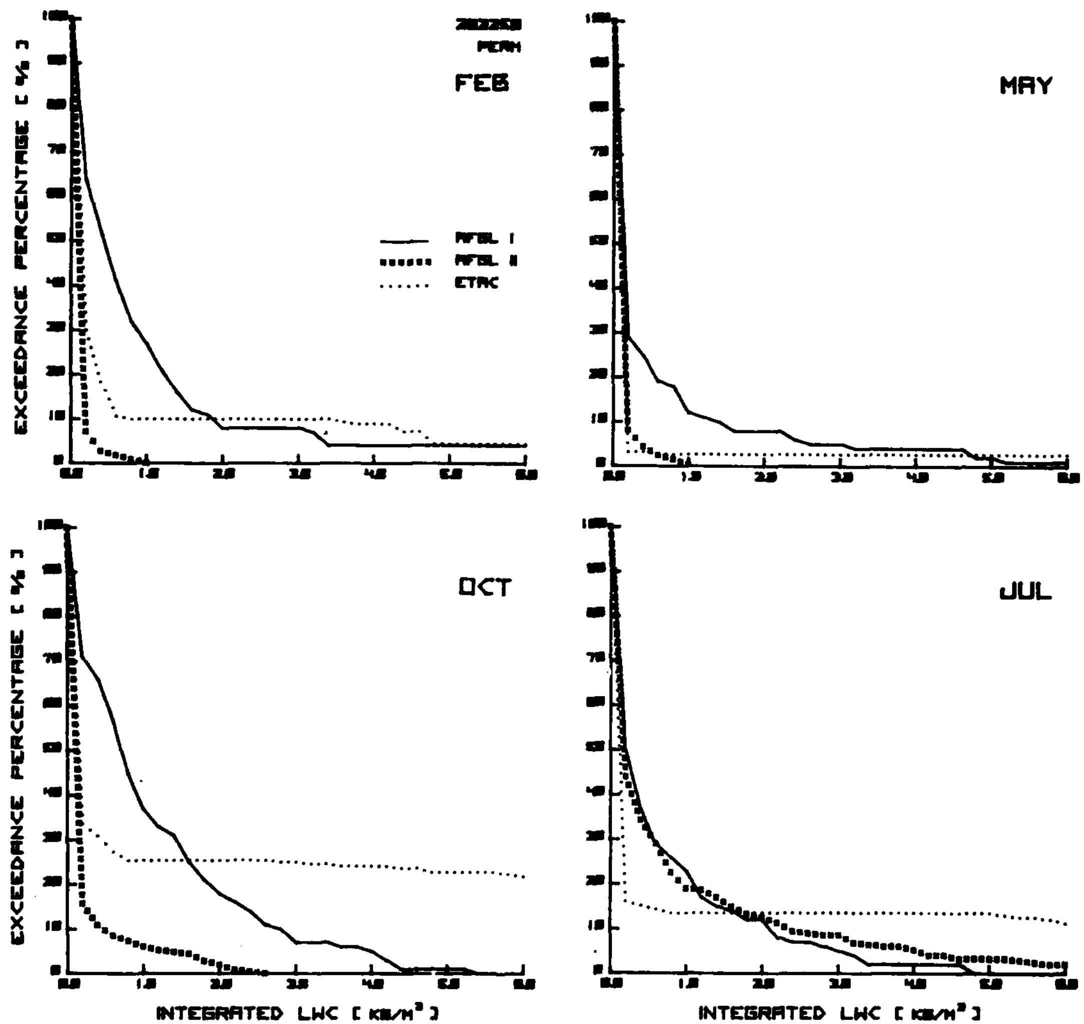

Figure A17. Cumulative Frequency Distribution of ILWC for Station 282250, Perm

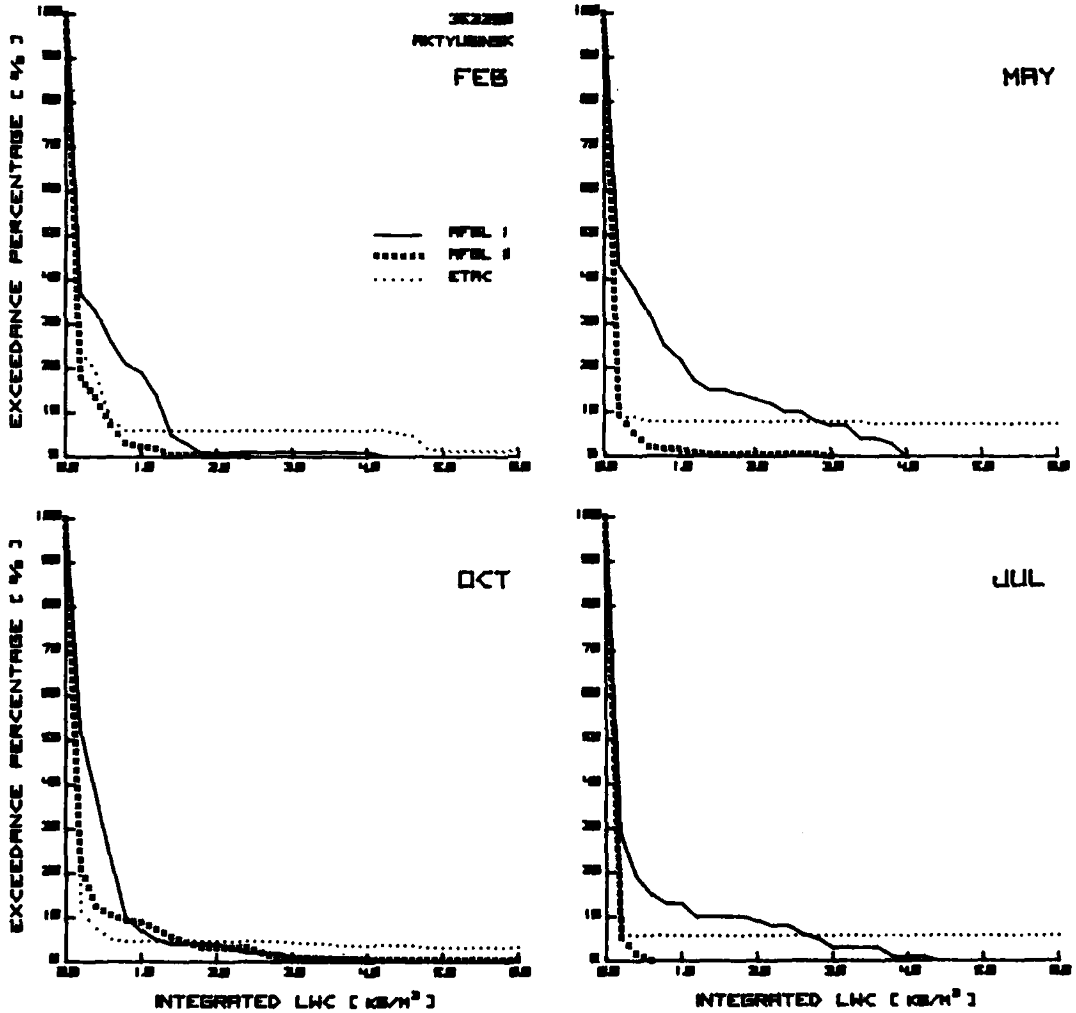

Figure A18. Cumulative Frequency Distribution of ILWC for Station 352290, Aktyubinsk

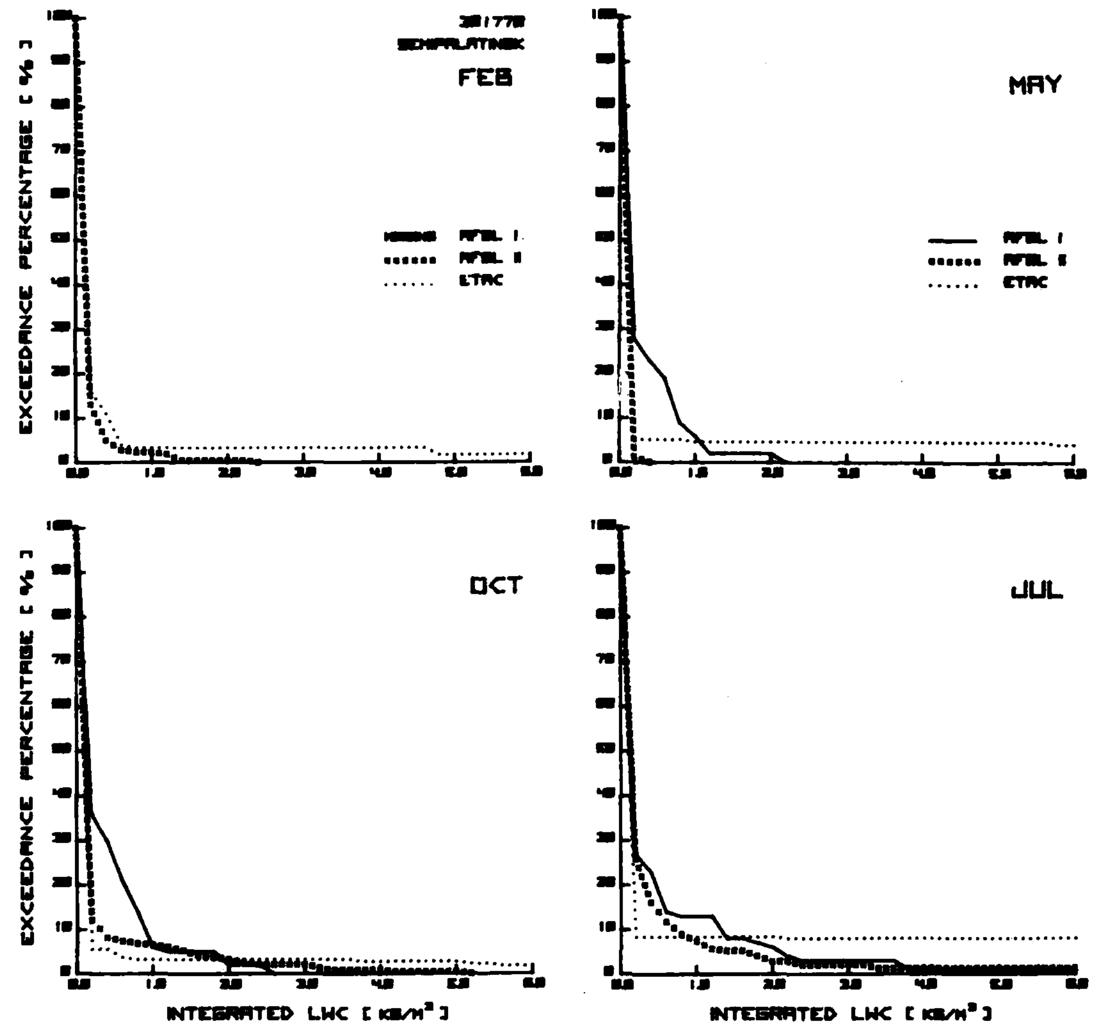

Figure A19. Cumulative Frequency Distribution of ILWC for Station 361770, Semipalatinsk

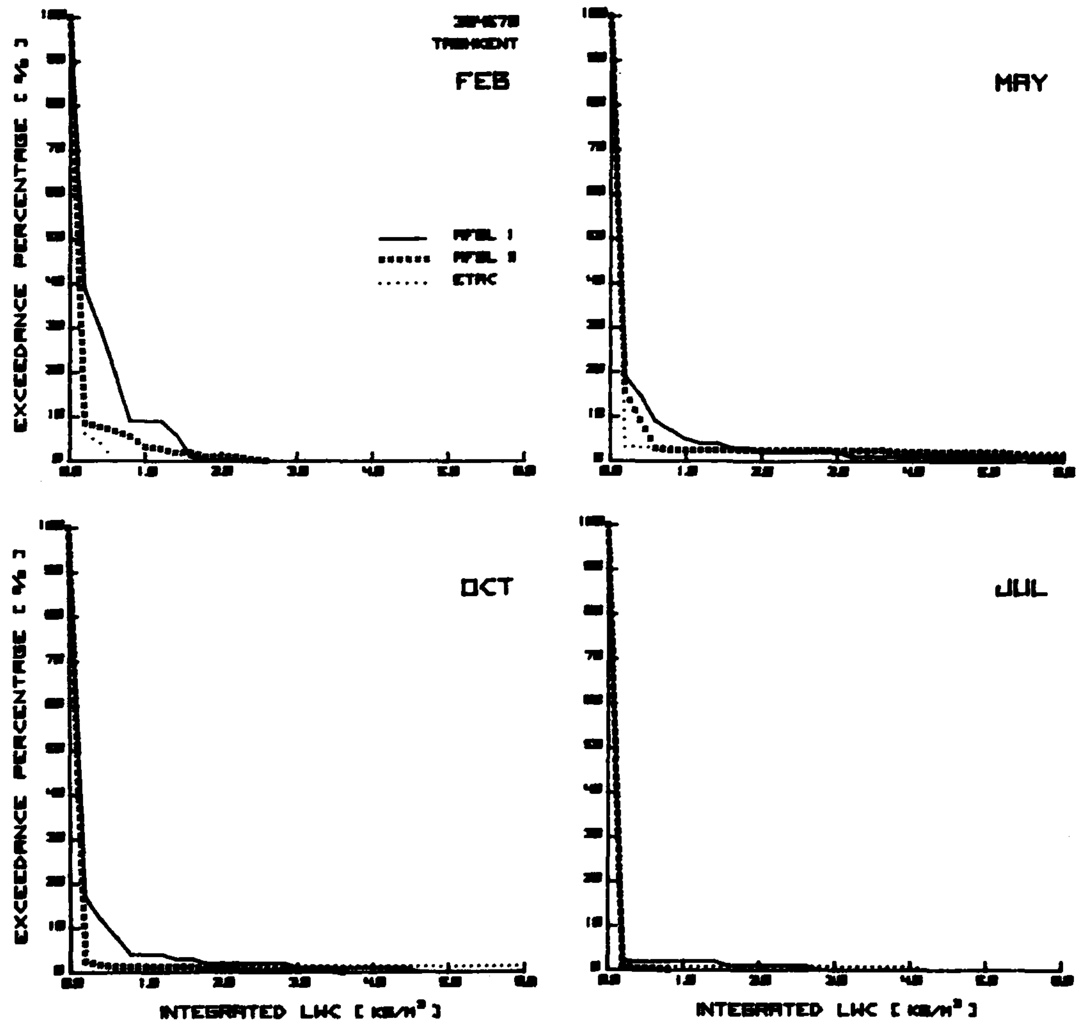

Figure A20. Cumulative Frequency Distribution of ILWC for Station 384570, Tashkent

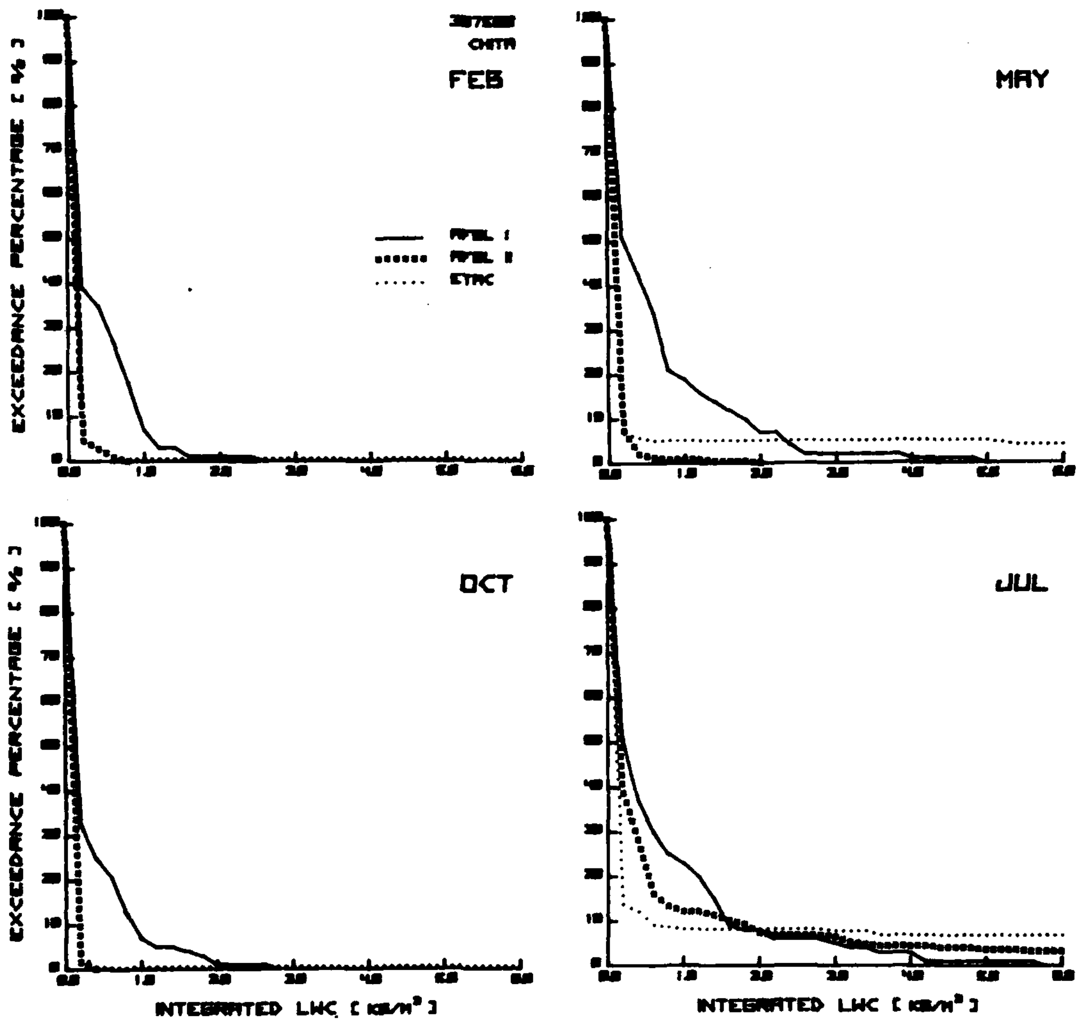

Figure A21. Cumulative Frequency Distribution of ILWC for Station 307580, Chita

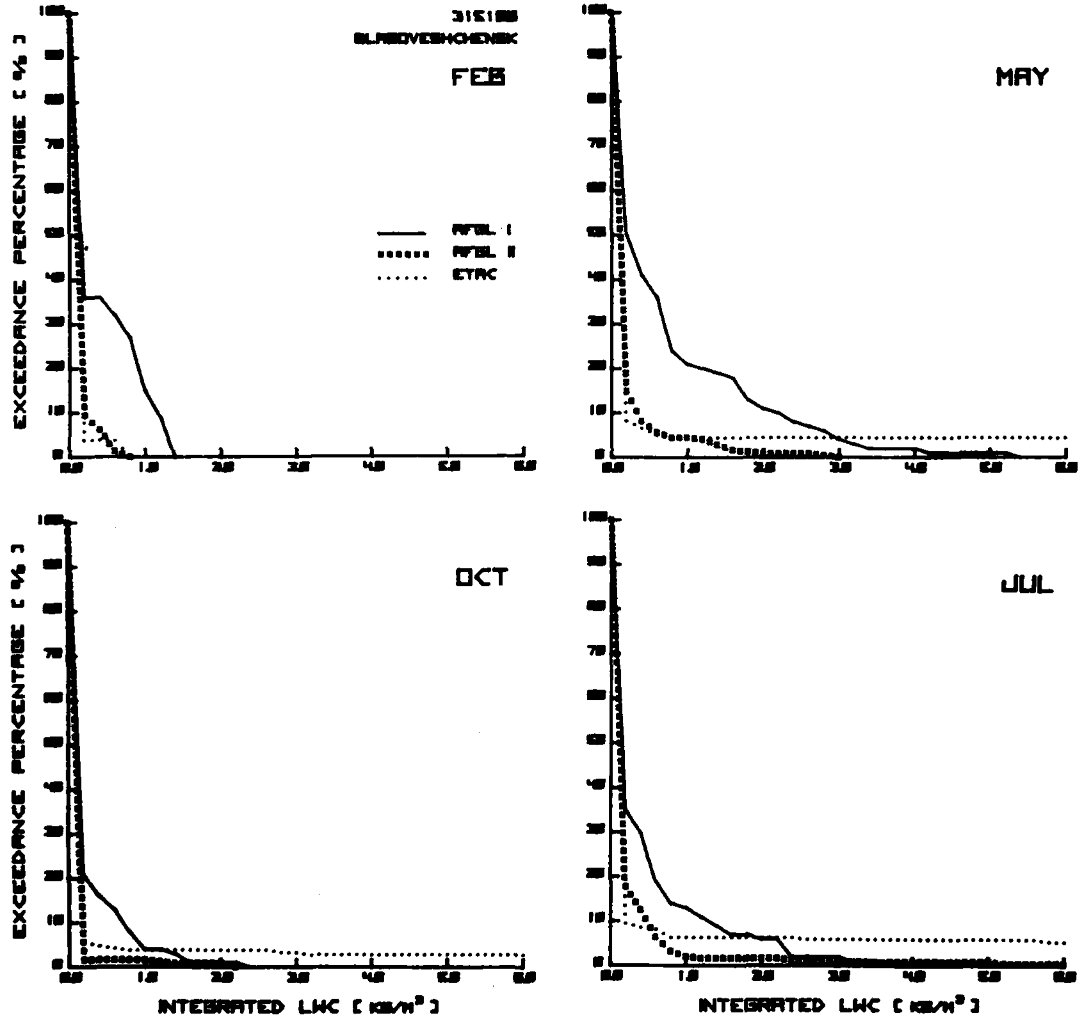

Figure A22. Cumulative Frequency Distribution of ILWC for Station 315100, Blagoveschensk

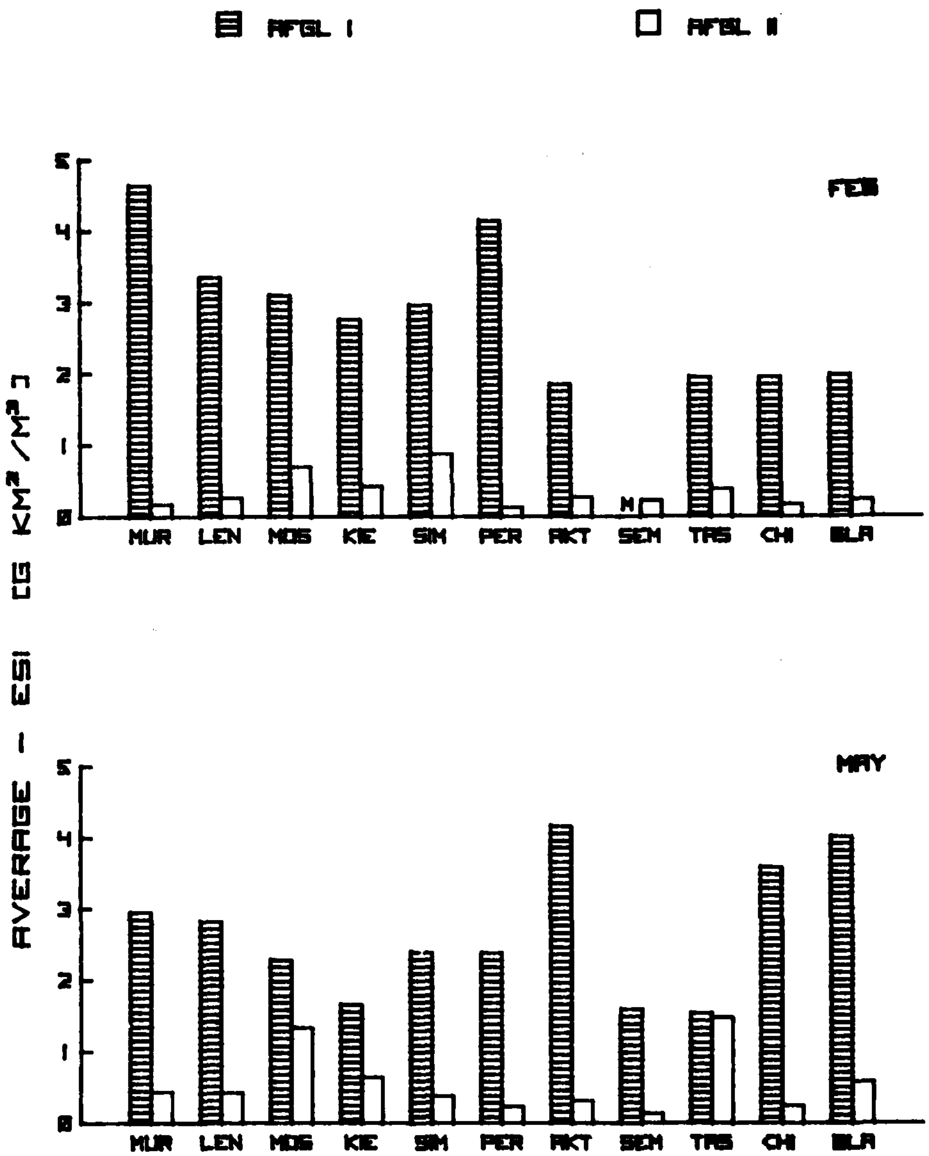

Figure A23. Comparison of AFGL-1 and AFGL-2 in Terms of Station Averages of ESI for February and May

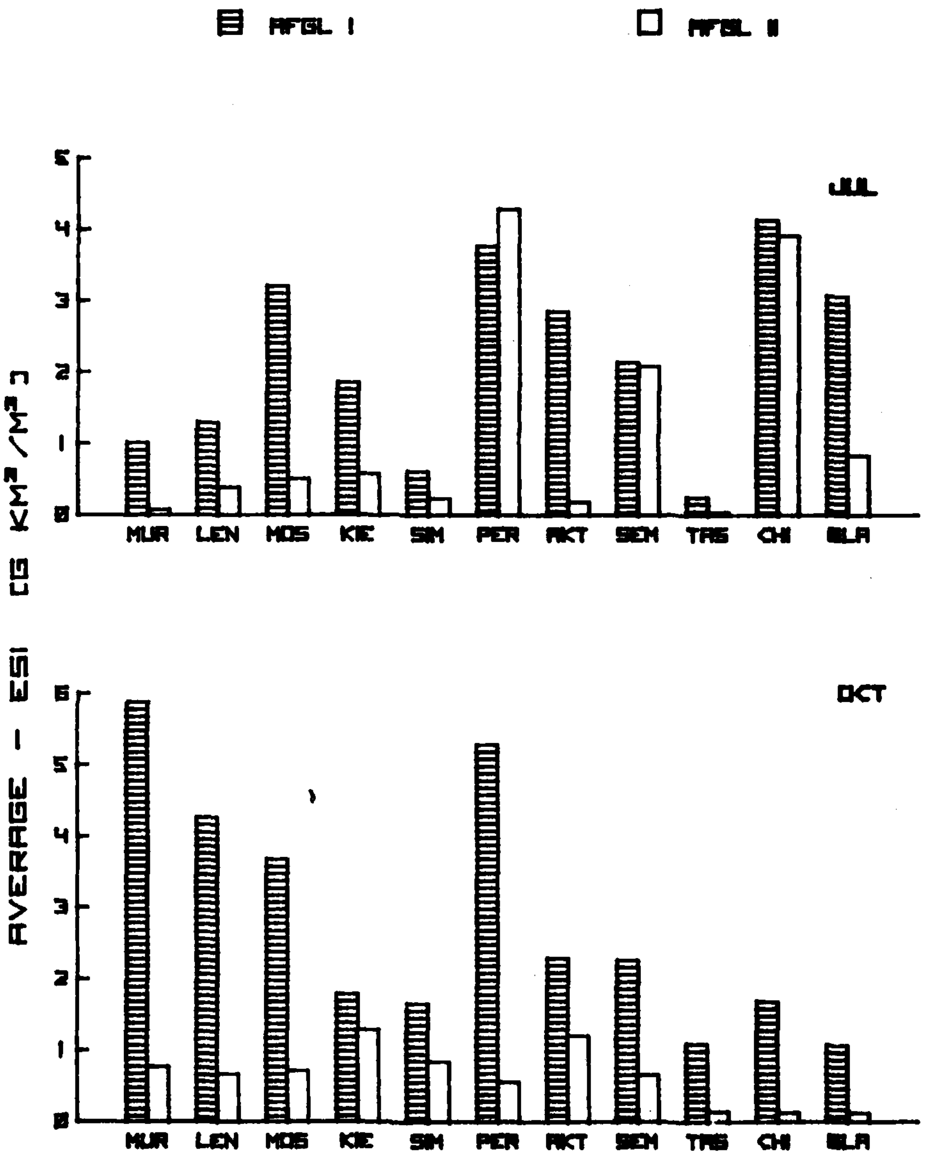

Figure A24. Comparison of AFGL-1 and AFGL-2 in Terms of Station Averages of ESI for July and October

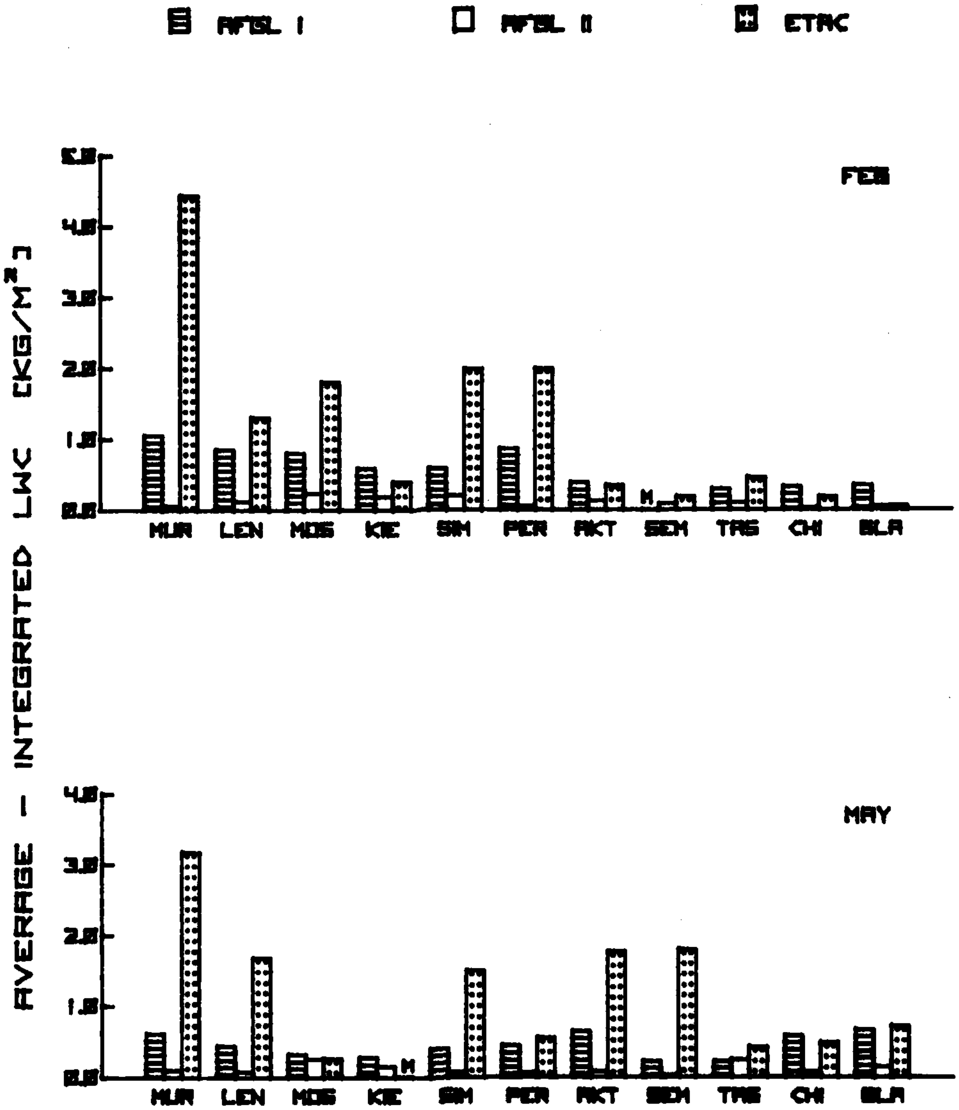

Figure A25. Comparison of the Three Models in Terms of Station Averages of ILWC for February and May

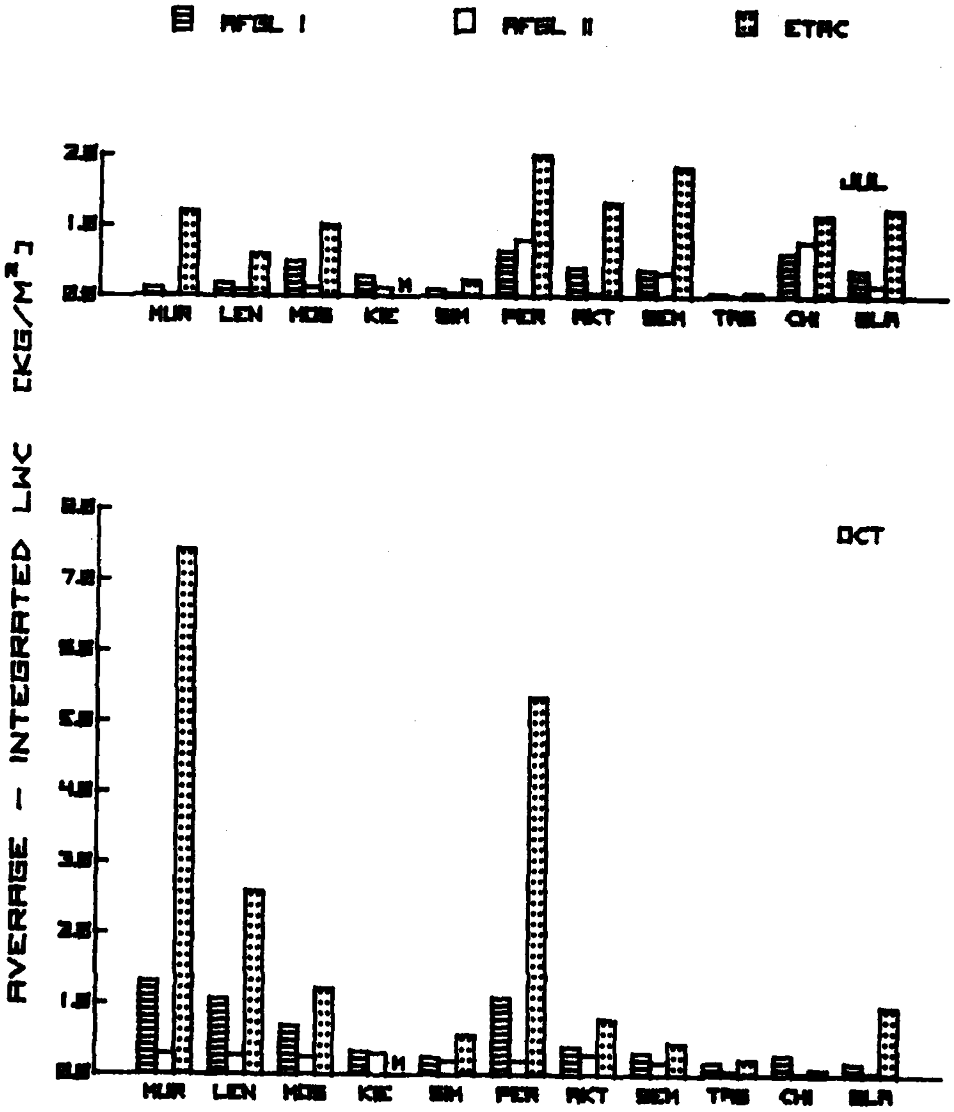

Figure A26. Comparison of the Three Models in Terms of Station Averages of ILWC for July and October